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The Cost of Implementing Ground-Based Fuel Tank Inerting in the Commercial Fleet

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16. Abstract

This report documents a cost analysis of ground-based fuel tank inerting for the commercial fleet performed by a group of industry experts lead by an Federal Aviation Administration (FAA) representative. Ground-based inerting (GBI) consists of displacing most of the oxygen dissolved in the fuel with nitrogen by a process called fuel scrubbing, and displacing the air in the empty space (ullage) of the fuel tank, with nitrogen-enriched air (NEA) in a process called ullage washing. The cost analysis considers the cost of implementing and performing GBI for all US departures carrying more than 19 passengers. The cost of GBI for only departures of airplanes with heated center wing tanks (HCWTs) was also determined. Airplanes that have the air conditioning equipment, or packs, located below the center wing fuel tanks are considered to have heated center wing tanks. This analysis considered all nonrecurring and recurring costs of GBI at all major U.S. airports over 10 years, with a 3-year start-up period. The cost of modifying the aircraft to allow for GBI was not considered in this analysis.

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EXECUTIVE SUMMARY

Since the TWA flight 800 accident in July 1996, more emphasis has been placed on determining methods for reducing the flammability of empty or near empty airplane fuel tanks. Inerting of fuel tanks with nitrogen or other inert gases has been practiced by the military for years to allow for increased survivability from ballistic impact. Some have speculated that commercial airplane operations could benefit from fuel tank inerting. However, the systems weight and resource requirements as well as low dispatch reliability have generally made fuel tank inerting not practical or cost effective for commercial aviation.

Ground-based inerting (GBI) involves fuel tank inerting on the ground only. This provides protection during ground operations and during the initial phases of flight where the exposure of the fuel tank to flammable vapors is usually greatest. It consists of displacing most of the oxygen dissolved in the fuel with nitrogen by a process called fuel scrubbing. It also requires displacing the air in the fuel tank empty space, also known as ullage, with nitrogen-enriched air (NEA) in a process called ullage washing. GBI could be accomplished by ground-based equipment, that resides at the airport, which would allow for increased cost effectiveness of the process with minimal impact on the airplane. The purpose of this research effort was to more accurately quantify the cost of implementing GBI for all US flights carrying more than 19 passengers. The cost of implementing GBI only for airplanes with heated center wing tanks (HCWTs) was also determined. Airplanes that have the air conditioning equipment, or packs, located below the center wing fuel tanks are considered to have heated center wing tanks. This analysis considered the cost of GBI over 10 years, with a 3-year start-up period. The cost of modifying the airplane to allow for GBI was not considered in this analysis.

To determine the cost of GBI, an industry team was assembled, lead by a Federal Aviation Administration (FAA) representative. The team possessed expertise in airports and aircraft ground operations, and state-of-the-art hollow fiber membrane (HFM) nitrogen generation technology. The cost of implementing GBI at Atlanta Hartsfield International Airport (ATL) and Atlantic City International Airport (ACY) were first determined. Using Department of Transportation (DOT) and FAA data, the cost was then extrapolated to all US airports that operate airplanes that carry more then 19 passengers.

The results of the cost analysis indicated that the cost of GBI for all flights over 19 passengers, at the nation's 400 largest airports, would be approximately 1.6 billion dollars. The cost of GBI for all airplanes with heated center wing tanks, which did not include fuel scrubbing with nitrogen, was determined to be approximately 800 million dollars. For the purpose of this study, aircraft with HCWTs were considered to be all Boeing airplane models manufactured in Boeing's facilities in the Seattle, Washington area (that is, not including the models manufactured in Long Beach, California) and all Airbus airplanes. Nonrecurring costs accounted for 37% of the cost of GBI for all US departures over 19 seats and 50% of the cost of GBI for HCWTs only. Labor accounted for 46% of the total cost of GBI for total applicable departures and 37% of the cost for inerting HCWT departures only. The cost of nitrogen for all applicable departures and HCWT departures only was 14% and 10% of the total cost, respectively.

1. INTRODUCTION.

1.1 BACKGROUND.

More emphasis has been placed on fuel tank safety since the TWA flight 800 accident in July 1996. Since the accident, the Federal Aviation Administration (FAA) has conducted research into methods that could eliminate or significantly reduce the exposure of transport airplanes to flammable vapors. This has included fuel tank inerting, which is commonly used by the military. However, the systems weight and resource requirements as well as perceived low dispatch reliability have indicated that fuel tank inerting would not be practical for application to transport airplanes. Additional FAA research is underway evaluating state of the art gas separation technology that could be used for onboard inerting systems to determine the applicability to transport airplanes.

More recently, a fuel tank harmonization working group (FTHWG) was charged by the Aviation Rulemaking Advisory Committee (ARAC) to perform a 6-month study of methods that could eliminate or significantly reduce the exposure of transport airplane fuel tanks to flammable vapors. The FTHWG was formed in response to a task assigned to the ARAC by the FAA. The FTHWG issued their report in July 1998. The report included a recommendation that the FAA perform a study of ground-based inerting (GBI) to further determine if it could be a practical method for reducing the flammability hazard of transport airplane fuel tanks [1]. Ground-based fuel tank inerting would involve some combination of fuel scrubbing and ullage washing while the airplane is on the ground if applied to all or most operating transport airplanes. It would only use ullage washing if applied to a limited number of airplanes, such as only those with heated center wing tanks (HCWTs). Airplanes that have the air conditioning equipment, or packs, located below the center wing fuel tanks are considered to have heated center wing tanks. The concept of GBI is to keep fuel tanks inert during ground operations and during the initial phases of flight where the exposure of the fuel tank to flammable vapors is usually greatest [2]. The FTHWG stated that the present level of safety of the wing fuel tanks was much greater than that of the center wing fuel tanks in the fleet. Thus, they recommended that fuel tank flammability reduction efforts focus on center wing tanks (CWTs).

1.1.1 Ullage Washing.

Ullage washing is a process that requires displacing the air in the fuel tank empty space, also known as ullage, with nitrogen gas or nitrogen-enriched air (NEA). NEA is a term used to describe low purity nitrogen (90%-98% pure), generally generated via a gas separation process. Ullage washing would be accomplished by providing the nitrogen or NEA to a supply line that feeds a simple fuel tank gas supply manifold.

1.1.2 Fuel Scrubbing.

Air, and particularly oxygen, readily dissolves in fuel. When a commercial transport airplane takes off after fueling, the resulting change in altitude causes a decrease in atmospheric pressure in the fuel tank. This decrease in pressure allows for some of the air to escape solution and enter the ullage space of the fuel tank. Since oxygen dissolves more readily than nitrogen, this can increase the oxygen concentration of the fuel tank ullage above ambient, although the total

amount of gas evolving from the fuel is small. This can have a profound effect on the fuel tank oxygen concentration for both inert fuel tanks as well as fuel tanks with ambient air in the ullage space. Fuel scrubbing is a process by which most of the oxygen dissolved in the fuel is displaced with nitrogen. Fuel and nitrogen are combined through a series of nozzles in a large container with the resulting combination having a very small amount of oxygen in solution. The military has used fuel scrubbing to allow for fuel tank inerting systems to operate more effectively and to increase survivability to ballistic impact in combat.

The fuel scrubbing process and purity of nitrogen can be varied to provide different amounts of fuel scrubbing protection. These different fuel scrubbing levels can cause variations in the cost of fuel scrubbing. It was assumed for this study that for sufficient protection, fuel scrubbing should provide that, regardless of the operational altitude of the aircraft, the fuel would never evolve gas with a greater oxygen concentration then 8 percent.

1.1.3 Hollow Fiber Membrane Gas Separation.

Hollow fiber membrane (HFM) technology provides the industrial gas industry with a cost–effective and efficient method for gas separation. Membranes separate gases by the principle of selective permeation across the membrane wall. For polymeric membranes, the rate of permeation of each gas is determined by its solubility in the membrane material, and the rate of diffusion through the molecular free volume in the membrane wall. Gases that exhibit high solubility in the membrane, and gases that are small in molecular size, permeate faster than larger, less soluble gases. "Fast" gases permeate through the membrane wall more readily than "slow" gases, thus separating the original gas mixture into two streams. HFMs are typically manufactured into hollow fibers to allow as much surface area as possible to be packaged into the smallest volume. A schematic of a HFM module can be seen in figure 1.

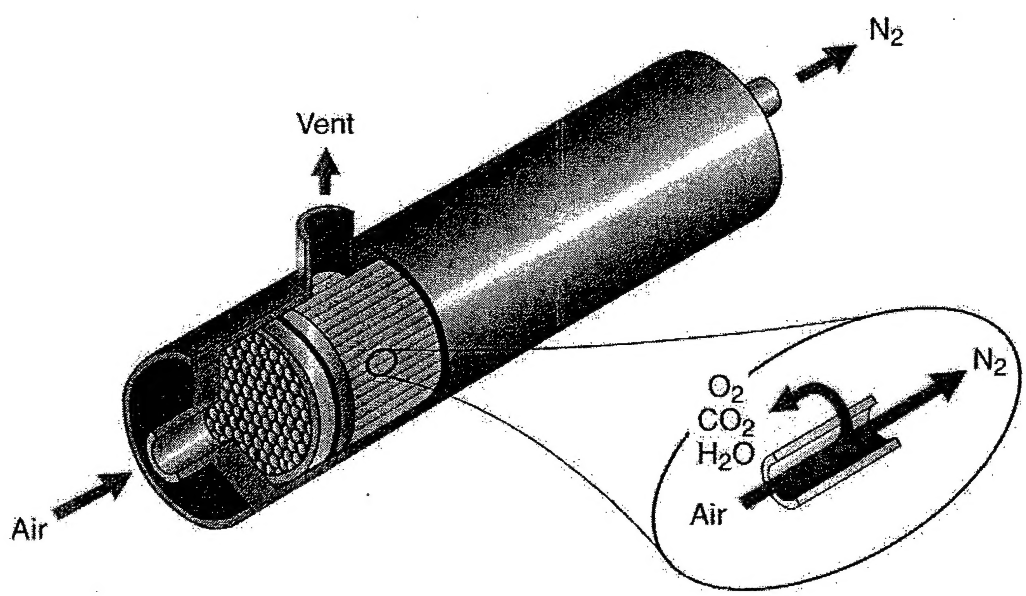

FIGURE 1. HOLLOW FIBER MEMBRANE BUNDLE DIAGRAM

The purity of the NEA stream can be adjusted by changing either the NEA flow rate, the feed air temperature, or pressure. The ability of a membrane to separate two gases is determined by its "selectivity," the ratio of permeabilities of the two gases. The higher the selectivity, the more efficient the separation and less energy is needed to run the system. HFM technology can be used to separate nitrogen (slow gas) from oxygen, carbon dioxide, and water vapor (fast gases). The primary benefit of HFM gas separation, when compared to the existing methods of gas separation, is simplicity of design. Large volumes of relatively pure NEA can be generated with no moving parts beyond those required to compress the air supply for the bundle. The primary draw back of HFM gas separation technology is the limitation on purity in nitrogen generation. Purity is generally limited to 99.9 percent nitrogen, with nitrogen purity higher than 99 percent becoming inefficient to obtain in terms of energy cost to generate the nitrogen. It should also be noted that systems using current HFM technology are capable of producing about 45 percent oxygen in the permeate, or fast gas stream.

1.1.4 Ground-Based Inerting (GBI).

GBI can be accomplished in two manners; either with on-aircraft equipment that operates while on the ground, with or without the aide of ground power units, or with on-the-ground equipment that either resides at the gate or is transported from aircraft to aircraft during servicing (i.e., nitrogen bottle cart).

The ARAC FTHWG final report stated that, on the ground, GBI posed the most economically viable method of improving the present level of safety in transport airplane fuel tanks. The ARAC FTHWG report stated that capitalizing on HFM gas separation technology should allow for nitrogen to be obtained at airports in a more cost-effective manner. The report stated that the committee did not have the requisite time and resources to accurately determine the industry-wide cost of implementing and sustaining GBI over the next 10 years but estimated it to be approximately 4 billion dollars. As a result of the ARAC FTHWG final report, the FAA committed to assembling experts from the airport, airline, and gas generation industries to perform a more detailed cost analysis of GBI.

This report details the cost analysis performed by a team of industry and FAA personnel to determine the cost of implementing, utilizing, and maintaining GBI over a 10-year period with a 3-year implementation period.

1.2 COST ANALYSIS TEAM.

The cost analysis team consisted of an FAA lead, having a background in aviation fire safety with knowledge in the area of fuel tank inerting, who was responsible for organizing the team efforts and documenting the cost analysis. The team also had a member from the gas generation industry with knowledge of ground inerting systems and their costs. A third member represented a US airline with knowledge of and access to the infrastructure and facilities of a large US airport. A fourth member represented the same airline and had knowledge of transport airplane operations and servicing (fueling, baggage, maintenance, etc.). The fifth and sixth members of the team represent a small airport with transport airplane traffic and have the same qualifications as the previous two members. Appendix A has a list of team members with a brief description of their qualifications.

1.3 SCOPE.

The purpose of this research effort is to more accurately quantify the cost of implementing and servicing airliners with GBI at all major airports in the United States. This was accomplished by accurately determining the cost of implementing the safety feature at Atlanta Hartsfield International airport (ATL) and Atlantic City International airport (ACY), then extrapolating the cost to all US airports which operate transport airplanes that carry more than 19 passengers.

The cost of GBI was calculated for all passenger departures with 19 or more seats. The cost of implementing GBI for only the center wing tanks of transport airplanes with HCWT was also determined. These two inerting scenarios were based on ARAC FTHWG studies and recommendations. This report describes the cost analysis in detail.

The analysis considers all recurring and nonrecurring costs associated with implementing the procedures as well as cost of the NEA and performing the inerting. No aircraft modification or certification costs were considered. All cost values are in terms of year 2000 dollars.

2. NITROGEN VOLUME REQUIREMENTS.

2.1 CALCULATION METHODS AND DATA.

Determining the amount of nitrogen each airport in the study would require over the prescribed 10-year period is essential to determining the cost of GBI. To allow for forecasted data to be applied, it was assumed that the 3-year implementation period would be 2000-2002, and the 10-year study period was 2003-2012. To determine the amount of nitrogen required at the two study airports, the amount of fuel serviced and the amount of fuel tank empty space, also known as ullage, on all departing commercial transport airplanes were calculated.

The amount of fuel serviced and remaining ullage were also calculated for only transport airplanes with a heated center wing tank (HCWT). This allowed for the calculation of the amount of nitrogen required to wash the center wing tank ullage of only heated center wing tank departures. For this study, this was assumed to be all Boeing airplanes, exclusive of former McDonnell Douglas models, and Airbus transport airplanes operating within the United States. Due to the practicality of the process, it was assumed that heated center wing tanks could not be loaded exclusively with scrubbed fuel. So the cost of scrubbing solely heated center wing tank fuel was not calculated independently and was not included in the cost data for HCWTs only.

2.1.1 Airport Departure Data.

The first step in determining these quantities was to determine the number and nature of departures at each study airport. Tables 1 and 2 give data compiled for daily airport departures by airplane model for both ATL and ACY. The departures were compiled in three aircraft type categories: single aisle, wide body, and commuter. It was believed that these three aircraft types had significantly different operational aspects with respect to average fuel loads and ullage space. Separation of departures and calculating averages with respect to these three categories allowed for a more accurate calculation of industry costs with respect to industry departure data. These tables also compile departures in terms of HCWT transport airplanes.

TABLE 1. COMPILED DAILY ATL DEPARTURE DATA

Single Aisle Aircraft			Wide Body Aircraft			Commuter Aircraft		
Aircraft Type	Number of Departures	Percentage Departures	Aircraft Type	Number of Departures	Percentage Departures	Aircraft Type	Number of Departures	Percentage Departures
Delta Single Aisle			Delta Wide Body			ASA Commuters		
B737	54	10.11%	L-1011	42	30.66%	CRJs	95	40.25%
MD88	223	41.76%	B777	4	2.92%	ATRs	47	19.92%
B757-200	116	21.72%	MD11	12	8.76%	BAZs	94	39.83%
B727S	141	26.40%	B767ER	18	13.14%	ASA Total	236	95.93%
B737-800	0	0.00%	B767-2/300	61	44.53%	Other Commuters	10	4.07%
Delta Total	534	70.17%	Delta Total	137	84.57%			
Other Airlines	227	29.83%	Other Airlines	25	15.43%			
Total =	761	100.00%	Total =	162	100.00%	Total =	246	100.00%
% Airport Departures =		65.10%	% Airport Departures =		13.86%	% Airport Departures =		21.04%
Total HCWT Departures =		425	Total HCWT Departures =		96	Total HCWT Departures =		0
% Airport HCWT Departures =		36.31%	% Airport HCWT Departures =		8.17%	% Airport HCWT Departures =		0.00%

TABLE 2. COMPILED DAILY ACY DEPARTURE DATA

Single Aisle Aircraft			Commuter Aircraft		
Aircraft Type	Number of Departures	Percentage Departures	Aircraft Type	Number of Departures	Percentage Departures
Single Aisle			Commuters		
B737	2	11.76%	B - 1900	12	66.67%
DC-9	10	58.82%	Jetstream 31	3	16.67%
MD80	3	17.65%	Metro 4	3	16.67%
B727	2	11.76%			
Total =	17		Total =	18	
% Airport Departures =		48.57%	% Airport Departures =		51.43%
Total HCWT Departures =		4	Total HCWT Departures =		0
% Airport HCWT Departures =		11.43%	% Airport HCWT Departures =		0.00%

Table 3 gives estimated peak daily and hourly departure data for ATL and ACY for both 1999 and 2012. The departure data for a busy day in 1999 at both ATL and ACY were calculated from airline departure data and this number was compared to the estimated average departures for 1999 FAA data from the office of policy and plans (APO data). The percent difference between the estimated annual average departures and the calculated average departures on a busy day was calculated and given in table 3. This percent difference was then used to approximate the busy day total departures from the FAA forecast data at ATL and ACY for the year 2012. The 2012 peak hourly data was estimated comparing the 1999 and 2012 busy day totals and relating that to the 1999 peak hourly data.

TABLE 3. ESTIMATED 2012 DEPARTURE DATA WITH EQUIVALENT 1999 DATA

	ATL		ACY	
Year	1999	2012	1999	2012
Busy Day Total	1169	1550	35	46
Busy Year Calculated	426685	565750	12775	16790
Predicted Yearly Departs	395000	523685	12000	15808
Percent Difference	8.02%	8.03%	6.46%	6.21%
Peak Hourly Departures	85	110	5	7
Sustained Peak Time Period	1.5	2	1	1

2.1.2 Average Fuel Service Quantity at Departure Calculation.

It was determined that the most practical method of determining the amount of fuel on departing commercial transport airplanes at ATL would be to characterize the average amount of fuel that is on each departure by aircraft type using available data from a major carrier at ATL with the supporting commuter carrier. To determine the average fuel serviced to each airplane at ATL for all airplane models, a "Fuel Distribution Summary" from this carrier was obtained for a busy day. This report summarizes the number of flights by airplane model and the total amount of fuel serviced to that model. An average fuel serviced per airplane model, by aircraft type, in gallons was calculated with a simple average and that number was converted to cubic feet for engineering purposes.

To determine the average fuel serviced to each commercial transport airplane at ACY for all types of aircraft, the average monthly fuel serviced per carrier was cross-referenced with aircraft operator models. From this information, an average fuel serviced per airplane model, by aircraft type, in gallons was calculated with a simple average and that number was converted to cubic feet for engineering purposes.

2.1.3 Average Ullage Space at Departure Calculation.

It was determined that the most practical method of determining the amount of ullage on departing commercial transport airplanes at ATL would be to characterize the average amount of ullage that is on each departure by airplane model. For ATL, it was determined that the only practical method for determining average ullage space at departure, by airplane model, was to add the average fuel serviced to an estimated average fuel load at arrival. This quantity was estimated by airplane model by examining the "Fuel Service Records" from the representative large carrier for a variety of flights and days. Each record gives the arriving, servicing, and

departing fuel quantities for a specific flight. An average fuel at arrival was then calculated for each airplane model. For the study commuter airplanes, this number had to be estimated from known operational observations.

This number was then added to the average fuel service quantity to determine the average fuel load at departure by airplane model in gallons. This number was then subtracted from the fuel tank volume of the airplane model in question to obtain the average ullage space at departure for each model of airplane in the representative carrier fleet operating at ATL. Again, this number was converted to cubic feet for engineering purposes.

For ACY the average ullage space volume at departure was calculated estimating the average fuel at arrival. This number was then added to the average fuel service quantity previously calculated to determine the average fuel load at departure by airplane model in gallons. This number was then subtracted from the fuel tank volume of the airplane model in question to obtain the average ullage space at departure for each type of airplane at ACY. Again, this number was converted to cubic feet for engineering purposes.

The actual fuel tank volume was estimated for each airplane model by converting the published airplane fuel capacities in pounds to cubic feet and then adding a small volume for fixed ullage space. All aircraft have a fixed amount of fuel tank space that cannot be filled. This number was estimated to be on average 3 percent of the fuel load for commercial transport style airplanes.

2.1.4 Weighted Average Calculations.

To obtain an average fuel added and ullage volume at departure for single aisle, wide-body, and commuter categories of aircraft, the calculated fuel added and ullage volumes were combined in a weighted average by airplane model for each category of aircraft. This weighted average was calculated for both all departures and HCWT departures only for ATL (appendix B, page B-3) and for ACY (appendix C, page C-2). For ATL, the weighted averages were based on the departure fraction of that aircraft category in the representative carrier's fleet. For ACY, the weighted averages were based on a typical departure profile based on airport departure data.

The average fuel serviced and ullage remaining per departure was calculated for the single aisle, wide-body, and commuter aircraft categories. This data was combined with the estimated 2012 departure data from table 3 and existing departure fraction data from tables 1 and 2 to determine the total fuel added and ullage remaining for ATL and ACY based on both busy daily and peak hourly data in the year 2012. This data is compiled in tables 4 and 5 for ATL and ACY respectively. Tables 6 and 7 give the equivalent data for center wing tanks of HCWT departures only. These values were used to determine the airport system requirements.

Appendix B provides detailed tables giving data calculated using the methods discussed in sections 2.1.2 and 2.1.3 for ATL. Appendix C gives the same calculated data for ACY.

2.2 ULLAGE-WASHING NITROGEN VOLUME.

To calculate the amount of nitrogen required for ullage washing, several sources were examined to determine the proper volume ratio of inerting nitrogen to inert a given volume of ullage.

TABLE 4. ESTIMATED 2012 TOTAL DEPARTURES FUEL ADDED AND ULLAGE REMAINING CALCULATIONS FOR ATL

Aircraft Category	Average Fuel Added (cubic feet)	Average Ullage Remaining (cubic feet)	Departure Fraction	Fuel Added (cubic feet)	Ullage Remain (cubic feet)
Daily					
Single Aisle	299.60	402.74	0.6510	302303.0	406375.4
Wide-body	1088.6	1322.8	0.1386	233836.2	284133.7
Commuter	69.106	151.91	0.2104	22540.7	49549.5
Totals			1.0000	558680.9	740058.6
Hourly (Based on Peak Data)					
Single Aisle	299.60	402.74	0.6510	21453.8	28839.5
Wide-body	1088.6	1322.8	0.1386	16594.8	20164.3
Commuter	69.106	151.91	0.2104	22540.7	3516.4
Totals			1.0000	39648.3	52520.2

TABLE 5. ESTIMATED 2012 TOTAL DEPARTURES FUEL ADDED AND ULLAGE REMAINING CALCULATIONS FOR ACY

Aircraft Category	Average Fuel Added (cubic feet)	Average Ullage Remaining (cubic feet)	Departure Fraction	Fuel Added (cubic feet)	Ullage Remain (cubic feet)
Daily					
Single Aisle	232.76	238.42	0.4857	5200.5	5326.9
Commuter	9.3279	44.930	0.5143	220.67	1062.9
Totals			1.0000	5421.2	6389.8
Hourly (Based on Peak Data)					
Single Aisle	232.76	238.42	0.4857	791.39	810.62
Commuter	9.3279	44.930	0.5143	33.580	161.75
Totals			1.0000	824.97	972.37

TABLE 6. ESTIMATED 2012 HCWT DEPARTURES FUEL ADDED AND ULLAGE REMAINING CALCULATIONS FOR ATL

Aircraft Category	Average Fuel Added (cubic feet)	Average Ullage Remaining (cubic feet)	Departure Fraction	Fuel Added (cubic feet)	Ullage Remain (cubic feet)
Daily					
Single Aisle	160.22	466.58	0.3631	90183.5	262615.3
Wide-body	449.55	543.57	0.0817	56924.2	68829.3
Totals			0.4448	147107.7	331444.6
Hourly (Based on Peak Data)					
Single Aisle	160.22	466.58	0.3631	6400.1	18637.2
Wide-body	449.55	543.57	0.0817	4039.8	4884.7
Totals			0.4448	10439.9	23521.9

TABLE 7. ESTIMATED 2012 HCWT DEPARTURES FUEL ADDED AND ULLAGE REMAINING CALCULATIONS FOR ACY

Aircraft Category	Average Fuel Added (cubic feet)	Average Ullage Remaining (cubic feet)	Departure Fraction	Fuel Added (cubic feet)	Ullage Remain (cubic feet)
Daily					
Single Aisle	100.26	371.12	0.1143	527.08	1951.1
Hourly (Based on Peak Data)					
Single Aisle	100.26	371.12	0.1143	80.208	296.90

HFM leased nitrogen generating systems operate more efficiently with increasing oxygen concentration, and an acceptable trade between NEA quality, flow, and efficiency is to allow the nitrogen generator to run at 95 percent purity. The ARAC has stated that a commonly accepted level of inerting for a fuel tank is approximately 9 percent oxygen concentration by volume. The ARAC FTHWG report also stated that research has indicated that a volumetric oxygen concentration of 10-11 percent provides "the same level of protection." For the purpose of this cost analysis, fuel tank oxygen concentrations below 10 percent constitute an inert fuel tank. To provide a conservative estimate for nitrogen cost, nitrogen requirements were calculated to allow for fuel tank oxygen concentrations of 8 percent by volume.

Recent FAA experiments have indicated that a 95 percent pure nitrogen volume to ullage space ratio of 1.5:1 is necessary to inert a fuel tank. This is to say that to inert a fuel tank that has x cubic feet of volume, 1.5x cubic feet of 95 percent pure nitrogen must be washed through the ullage to obtain an oxygen concentration in the tank of 8 percent. To obtain the volume of ullage-washing nitrogen required, the above stated relationship (1.5x the ullage calculated) was applied to the ullage remaining at departure data calculated in tables 4 through 7 for both study airports for all departures and HCWT departures only.

Table 8 gives the calculated ullage-washing volume of nitrogen required at ATL on a daily and hourly basis for both all departures and HCWT departures only based on the FAA-forecasted 2012 departure data given in table 3. This table also includes the average ullage-washing volume required per departure for the three categories of aircraft previously stated, calculated from the average ullage remaining data given in tables 4 and 6. Table 9 gives the same data for ACY also based on the FAA-forecasted 2012 departure data given in table 3. Again, this table includes the average ullage-washing volume required per departure for the three categories of aircraft previously stated, calculated from the average ullage remaining data given in tables 5 and 7.

To determine the amount of nitrogen required on a yearly basis for ullage washing, the volume requirement averages per departure by aircraft category (tables 8 and 9) were applied to the FAA APO forecast data for the two study airports for the years 2003-2012. The two categories of APO forecasting pertaining to commercial passenger flights are Commercial Air movements and Commuter/Air Taxi movements. The sum of these numbers is the commercial aircraft movements. Departures were obtained by dividing movements by two. To obtain the estimated amount of departures applicable to GBI, it was assumed that 10 percent of the total movements were cargo aircraft or aircraft with less then 19 seats for both ATL and ACY. Total GBI applicable yearly departures was obtained by subtracting 10 percent from the sum of Commercial Air movements and Commuter/Air Taxi movements and dividing this number by 2.

TABLE 8. CALCULATED NITROGEN REQUIREMENTS FOR ATL

	All Departures				HCWT Washing Only	
	Ullage Remaining (cubic feet)	Ullage Wash Requirement (cubic feet)	Fuel Added (cubic feet)	Fuel Scrub Requirement (cubic feet)	Ullage Remaining (cubic feet)	Ullage Wash Requirement (cubic feet)
System Requirements						
Daily	740058.6	1110087.9	558680.9	513986.5	331444.6	497166.9
Hourly	52520.29	78780.43	39648.32	36476.46	23521.88	35282.81
Departure Averages						
Wide-body	1322.789	1984.184	1088.628	1001.538	543.566	815.350
Single Aisle	402.7407	604.1111	299.6002	275.6321	466.5790	699.8686
Commuter	151.9102	227.8653	69.1058	63.5773	0.0000	0.0000

TABLE 9. CALCULATED NITROGEN REQUIREMENTS FOR ACY

	All Departures				HCWT Washing Only	
	Ullage Remaining (cubic feet)	Ullage Wash Requirement (cubic feet)	Fuel Added (cubic feet)	Fuel Scrub Requirement (cubic feet)	Ullage Remaining (cubic feet)	Ullage Wash Requirement (cubic feet)
System Requirements						
Daily	6389.81	9584.71	5421.21	4987.51	1951.05	2926.58
Hourly	972.362	1458.543	824.966	758.969	296.899	445.349
Departure Averages						
Single Aisle	238.416	357.625	232.760	214.140	371.124	556.686
Commuter	44.9295	67.3943	9.3279	8.5817	0.0000	0.0000

Tables 10 and 11 give 2003-2012 APO forecasts and the resulting estimated departures for ATL and ACY respectively.

$$\text{Total Applicable Departures} = \frac{[\text{Com Air} + \text{AT and Comm}] - [0.1 * (\text{Com Air} + \text{AT and Comm})]}{2}$$

The total departures from tables 10 and 11 were broken into wide-body, single aisle, and commuter departures based on the averages in tables 1 and 2 for ATL and ACY respectively. The averages from tables 8 and 9 for ullage washing were applied to the aircraft category departure data to obtain a volume of nitrogen for each aircraft category on a yearly basis. The sum of these numbers is the total nitrogen required for the forecasted year for ullage washing. Tables 12 and 13 give the total ullage washing nitrogen calculated for all applicable departures on a yearly basis for ATL and ACY respectively. Tables 14 and 15 give the total ullage-washing nitrogen calculated for all HCWT departures only on a yearly basis for ATL and ACY respectively.

TABLE 10. PREDICTED ATL DEPARTURES DATA CALCULATED FROM FAA DATA

Year	Projected Air Carrier	Projected AT & Comm.	Estimated Departures
2003	740415	191146	419202
2004	763433	193925	430811
2005	786451	196705	442420
2006	809470	199485	454030
2007	832488	202265	465639
2008	855507	205045	477248
2009	878525	207825	488858
2010	901543	210604	500466
2011	924562	213384	512076
2012	947580	216164	523685
		Total	4,714,435

TABLE 11. PREDICTED ACY DEPARTURES DATA CALCULATED FROM FAA DATA

Year	Projected Air Carrier	Projected AT & Comm.	Estimated Departures
2003	15041	15090	13559
2004	15505	15181	13809
2005	15968	15273	14058
2006	16432	15365	14309
2007	16896	15456	14558
2008	17359	15548	14808
2009	17823	15640	15058
2010	18286	15731	15308
2011	18750	15823	15558
2012	19214	15915	15808
		Total	146,833

TABLE 12. CALCULATED ULLAGE-WASHING NITROGEN VOLUME FOR ATL—ALL APPLICABLE DEPARTURES

	Departures				Nitrogen Volume (cubic feet)			
Year	Total Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N2 Volume
2003	419,202	58,688	272,481	88,032	116,449,285	164,608,678	20,059,948	301,537,113
2004	430,811	60,314	280,027	90,470	119,674,126	169,167,202	20,615,470	309,887,608
2005	442,420	61,939	287,573	92,908	122,898,967	173,725,725	21,170,992	318,238,104
2006	454,030	63,564	295,120	95,346	126,124,086	178,284,641	21,726,561	326,589,318
2007	465,639	65,189	302,665	97,784	129,348,927	182,843,165	22,282,083	334,939,813
2008	477,248	66,815	310,211	100,222	132,573,767	187,401,688	22,837,605	343,290,309
2009	488,858	68,440	317,758	102,660	135,798,886	191,960,604	23,393,175	351,641,523
2010	500,466	70,065	325,303	105,098	139,023,449	196,518,735	23,948,649	359,991,299
2011	512,076	71,691	332,849	107,536	142,248,568	201,077,651	24,504,219	368,342,514
2012	523,685	73,316	340,395	109,974	145,473,409	205,636,174	25,059,741	376,693,009
Totals	4,714,435	660,021	3,064,383	990,031	1,309,613,470	1,851,224,263	225,598,444	3,391,150,612

TABLE 13. CALCULATED ULLAGE-WASHING NITROGEN VOLUME FOR ACY—ALL APPLICABLE DEPARTURES

	Departures				Nitrogen Volume (cubic feet)			
Year	Total Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N2 Volume
2003	13,559	0	6,644	6,915	0	2,375,995	466,036	2,855,590
2004	13,809	0	6,766	7,043	0	2,419,804	474,628	2,908,241
2005	14,058	0	6,888	7,170	0	2,463,437	483,187	2,960,681
2006	14,309	0	7,011	7,298	0	2,507,420	491,814	3,013,543
2007	14,558	0	7,133	7,425	0	2,551,054	500,372	3,065,984
2008	14,808	0	7,256	7,552	0	2,594,862	508,965	3,118,635
2009	15,058	0	7,378	7,680	0	2,638,671	517,558	3,171,286
2010	15,308	0	7,501	7,807	0	2,682,479	526,150	3,223,937
2011	15,558	0	7,623	7,935	0	2,726,287	534,743	3,276,589
2012	15,808	0	7,746	8,062	0	2,770,096	543,336	3,329,240
Totals	146,833	0	71,948	74,885	0	25,730,105	5,046,788	30,923,726

TABLE 14. CALCULATED ULLAGE-WASHING NITROGEN VOLUME FOR ATL—HCWT DEPARTURES ONLY

	HCWT Departures				Nitrogen Volume (cubic feet)			
Year	Total Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N2 Volume
2003	419,202	34,375	152,170	0	28,027,301	106,499,446	0	134,713,292
2004	430,811	35,327	156,384	0	28,803,463	109,448,745	0	138,443,919
2005	442,420	36,278	160,598	0	29,579,626	112,398,044	0	142,174,547
2006	454,030	37,230	164,813	0	30,355,856	115,347,597	0	145,905,496
2007	465,639	38,182	169,027	0	31,132,018	118,296,896	0	149,636,124
2008	477,248	39,134	173,241	0	31,908,181	121,246,195	0	153,366,752
2009	488,858	40,086	177,455	0	32,684,410	124,195,749	0	157,097,701
2010	500,466	41,038	181,669	0	33,460,506	127,144,794	0	160,828,007
2011	512,076	41,990	185,884	0	34,236,736	130,094,347	0	164,558,956
2012	523,685	42,942	190,098	0	35,012,898	133,043,646	0	168,289,584
Totals	4,714,435	386,584	1,711,340	0	315,200,995	1,197,715,459	0	1,515,014,378

TABLE 15. CALCULATED ULLAGE-WASHING NITROGEN VOLUME FOR ACY—HCWT DEPARTURES ONLY

	Departures				Nitrogen Volume (cubic feet)			
Year	Total Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N2 Volume
2003	13,559	0	1,546	0	0	860,490	0	862,036
2004	13,809	0	1,574	0	0	876,356	0	877,930
2005	14,058	0	1,603	0	0	892,158	0	893,761
2006	14,309	0	1,631	0	0	908,087	0	909,718
2007	14,558	0	1,660	0	0	923,889	0	925,549
2008	14,808	0	1,688	0	0	939,755	0	941,443
2009	15,058	0	1,717	0	0	955,621	0	957,337
2010	15,308	0	1,745	0	0	971,486	0	973,232
2011	15,558	0	1,774	0	0	987,352	0	989,126
2012	15,808	0	1,802	0	0	1,003,218	0	1,005,020
Totals	146,833	0	16,739	0	0	9,318,413	0	9,335,152

2.3 FUEL-SCRUBBING NITROGEN VOLUME.

To calculate the amount of nitrogen required per departure for the wide-body, single aisle, and commuter airplane categories, a ratio of nitrogen required to fuel pumped was obtained. The manufacturer of a common fuel scrubber stated that the process requires approximately 0.92 to 1 nitrogen to fuel ratio by volume of 99.5 percent pure nitrogen to scrub the fuel to a level commensurate with the projected inerting levels assumed for the study. To obtain the volume of fuel-scrubbing nitrogen required, the above stated relationship (0.92x the fuel volume calculated) was applied to the fuel added for departure data calculated in tables 4 and 5 for both study airports, for all departures.

Table 8 gives the calculated fuel-scrubbing volume of nitrogen required at ATL on a daily and hourly basis for all departures based on the FAA-forecasted 2012 departure data given in table 3. This table also includes the average fuel-scrubbing volume required per departure for the three categories of airplanes previously stated, calculated from the average fuel added data given in tables 4 and 6. Table 9 gives the same data for ACY also based on the FAA-forecasted 2012 departure data given in table 3. Again, this table includes the average fuel-scrubbing nitrogen volume required per departure for the three categories of airplanes previously stated, calculated from the average fuel added data given in tables 5 and 7. Tables 16 and 17 give the total fuel-scrubbing nitrogen calculated for all applicable departures on a yearly basis for ATL and ACY respectively.

3. SYSTEM ARCHITECTURE.

3.1 ATLANTA HARTSFIELD INTERNATIONAL AIRPORT (ATL).

Calculation of the nitrogen requirements for ATL described in the previous section, along with the specific airport layout, allowed for the development of the nitrogen system architecture that best suited ATL. Factors such as nonrecurring cost, operational efficiency, and airport operational interruptions were all considered when determining the best method of nitrogen generation and distribution at ATL. Appendix D (part I, page D-1) gives a more detailed description of equipment and systems as specified by a large gas manufacturer for a model large airport.

3.1.1 Fuel-Scrubbing System and Methods.

Fuel scrubbing at ATL would be accomplished by placing a large fuel scrubber at the fuel farm. The airport has an extensive hydrant system that supplies fuel directly to each gate from the fuel farm via a network of underground pipes. A truck or large handcart is then used to meter the fuel to each individual aircraft. The fuel would pass through the scrubber as it is pumped from the fuel farm to the main supply of the fuel hydrant system. A large valve will divert fuel leaving the fuel farm, through the fuel-scrubbing system. The fuel will pass through the scrubber unit and then be diverted back to the main hydrant supply line.

Nitrogen will be supplied by a large membrane gas separation system that will be leased from a large-scale gas supplier. The airport will prepare the sight for the system, by providing a concrete pad site and system power and mechanical connection. The fuel scrubber will be

TABLE 16. CALCULATED FUEL-SCRUBBING NITROGEN VOLUME FOR ATL

	Departures				Nitrogen Volume (cubic feet)			
Year	Total Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N2 Volume
2003	419,202	58,688	272,481	88,032	58,776,312	75,104,021	5,596,837	139,477,170
2004	430,811	60,314	280,027	90,470	60,404,010	77,183,883	5,751,831	143,339,725
2005	442,420	61,939	287,573	92,908	62,031,708	79,263,746	5,906,825	147,202,279
2006	454,030	63,564	295,120	95,346	63,659,546	81,343,788	6,061,832	151,065,166
2007	465,639	65,189	302,665	97,784	65,287,244	83,423,650	6,216,825	154,927,720
2008	477,248	66,815	310,211	100,222	66,914,942	85,503,513	6,371,819	158,790,274
2009	488,858	68,440	317,758	102,660	68,542,780	87,583,555	6,526,826	162,653,161
2010	500,466	70,065	325,303	105,098	70,170,338	89,663,238	6,681,807	166,515,383
2011	512,076	71,691	332,849	107,536	71,798,176	91,743,280	6,836,814	170,378,270
2012	523,685	73,316	340,395	109,974	73,425,874	93,823,143	6,991,807	174,240,824
Totals	4,714,435	660,021	3,064,383	990,031	661,010,931	844,635,817	62,943,223	1,568,589,972

TABLE 17. CALCULATED FUEL-SCRUBBING NITROGEN VOLUME FOR ACY

	Departures				Nitrogen Volume (cubic feet)			
Year	Total Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N2 Volume
2003	13,559	0	6,644	6,915	0	1,422,727	59,343	1,482,070
2004	13,809	0	6,766	7,043	0	1,448,959	60,437	1,509,396
2005	14,058	0	6,888	7,170	0	1,475,086	61,527	1,536,613
2006	14,309	0	7,011	7,298	0	1,501,423	62,626	1,564,049
2007	14,558	0	7,133	7,425	0	1,527,551	63,716	1,591,266
2008	14,808	0	7,256	7,552	0	1,553,783	64,810	1,618,592
2009	15,058	0	7,378	7,680	0	1,580,015	65,904	1,645,919
2010	15,308	0	7,501	7,807	0	1,606,247	66,998	1,673,245
2011	15,558	0	7,623	7,935	0	1,632,479	68,092	1,700,571
2012	15,808	0	7,746	8,062	0	1,658,711	69,186	1,727,898
Totals	146,833	0	71,948	74,885	0	15,406,981	642,639	16,049,620

located in proximity to the nitrogen generation system. It does not require electrical power beyond monitor and controls systems but will need a pad site with mechanical connections.

3.1.2 Ullage-Washing System and Methods.

To provide nitrogen for ullage washing to the aircraft, each concourse will have a large commercial off-the-shelf HFM nitrogen generator. The unit, with its associated compressor, will be placed elevated at the end of each concourse. The system will charge a large surge tank. The surge tank will supply nitrogen directly to the gates during times of low operations. The surge tank also provides a valuable reserve in times of peak operational nitrogen requirements.

The surge tank will be plumbed to every gate in the concourse with a rigid manifold, mounted exterior to the concourse. The nitrogen will be plumbed from the concourse to the end of each loading bridge through a flexible connection. The nitrogen would be run through festoons, mounted exterior to the loading bridge, to the delivery system mounted under the passenger loading area of the bridge.

The nitrogen delivery system would consist of a 100-foot hose reel, which is mounted external to the underside of the passenger loading area, with a programmable nitrogen-metering unit. The programmable metering unit would control an in-line solenoid valve to allow for control of the nitrogen flow to the aircraft.

To provide nitrogen for ullage washing at the commuter terminal at ATL, a special delivery system had to be developed because commuter passengers do not board through traditional loading bridges. ATL commuter passengers obtain access to the aircraft via a system of ground level doors, with each servicing several different commuter parking spaces. These doors have a moving walkway that allows sheltered access to each commuter aircraft. The walkway would be modified to carry the nitrogen supply via a boom and flexible-piping configuration. This moving walkway would also have a hose reel and programmable metering device.

3.2 ATLANTIC CITY INTERNATIONAL AIRPORT (ACY).

Calculation of the nitrogen requirements for ACY described in the previous section, along with the specific airport layout, allowed for the development of an architecture that best suited ACY. Factors such as nonrecurring cost, operational efficiency, and airport operational interruptions were all considered when determining the best method of nitrogen generation and distribution at ACY. Appendix D (part II, page D-5) gives a more detailed description of equipment and systems as specified by a large gas manufacturer for a model small airport.

3.2.1 Fuel-Scrubbing System and Methods.

Fuel scrubbing at ACY would be accomplished by placing a portable fuel scrubbing unit in tow with the fuel truck. The fuel truck would be modified to provide fuel to the portable scrubbing unit, and then dispense the scrubbed fuel via the trucks existing pumping system.

Nitrogen will be supplied by a small HFM gas separation system that will be mounted with the scrubbing equipment in tow. For the purpose of the study, it is assumed that the nitrogen is purchased by volume from a leased system.

3.2.2 Ullage-Washing System and Methods.

To provide nitrogen for ullage washing to the airplane, the concourse will have a commercial off-the-shelf HFM gas separation unit. The unit, with its associated compressor, will be placed in front of the main concourse adjacent to the aircraft operations area (AOA). The system will charge a surge tank. The surge tank will supply nitrogen to the gates during times of low operations.

The surge tank will be plumbed to every gate in the concourse with rigid manifold, mounted exterior to the concourse. The nitrogen will be plumbed from the concourse to the end of each loading bridge through a flexible connection. The nitrogen would be run through festoons, mounted exterior to the loading bridge, to the delivery system mounted under the passenger loading area of each bridge. Figure 2 illustrates the basic nitrogen distribution layout envisioned at ACY.

The nitrogen delivery system would consist of a 100-foot hose reel, which is mounted external to the underside of the passenger loading area, with a programmable nitrogen-metering unit. The programmable metering unit would control an in-line solenoid valve to allow for control of nitrogen flow to the airplane.

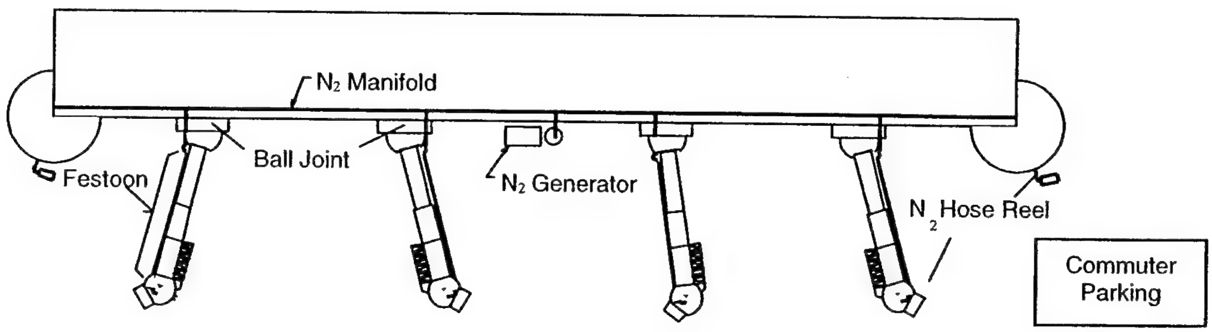

FIGURE 2. ILLUSTRATION OF CONCEPTUAL ACY DISTRIBUTION SYSTEM

To provide nitrogen for ullage washing to the commuter parking area at ACY, the rigid manifold will be extended via an underground trench to two separate commuter parking areas, each servicing several aircraft simultaneously. A large handhole will be utilized to house the hose reel and metering unit for the commuter areas.

3.3 SYSTEM OPERATION.

Fuel scrubbing will occur automatically with no human interaction beyond the initial equipment purchase and modification. Ullage washing will require airport personnel to perform a task to allow for the dispensing of nitrogen into the fuel tanks. This task assumes that all requisite airplanes have been modified with a nitrogen-dispensing manifold connected to a nitrogen fill port, mounted exterior to the aircraft. This fill port would be recessed in a panel on the underside of the airplane forward of the wing.

To perform an ullage wash of an airplane, the system operator would first disconnect the hose reel from the loading bridge underside, reel out the necessary amount of hose and attach the nitrogen fitting to the nitrogen fill port on the underside of the forward section of the aircraft. Next, the operator would use the programmable metering unit to select the amount of nitrogen to be dispensed. This would most likely be accomplished by selecting an airplane model and fuel load from a series of menu buttons. The nitrogen would then proceed to dispense itself without further operator interaction. After the nitrogen is dispensed, the operator would then disconnect the supply line from the aircraft and redeposit the hose on the reel. The total work time of the operator is assumed to take about 10 minutes. Ullage washing is assumed to take no more than 20 minutes.

4. AIRPORT COST ANALYSIS.

The cost of implementing and performing GBI at ATL and ACY consist of two primary categories: nonrecurring and recurring costs. Nonrecurring costs are those costs associated with implementing the capability at the airport. These include modifying each concourse and gate, installation of the nitrogen generation system(s) and fuel scrubber, and any engineering and construction costs. Recurring costs are those costs that will be incurred on an annual basis and are associated with performing the inerting task on the aircraft. They include volume nitrogen costs, operator labor costs, and system maintenance costs.

Tables 18 and 19 give a summary of the costs associated with GBI at ATL and ACY respectively. The following sections describe the methods for determining the costs associated with each cost category.

TABLE 18. SUMMARY OF GBI COST FOR ATL

	Full GBI	Washing HCWTs Only
Nonrecurring Costs		
Engineering/Architectural	$250,000	$250,000
Concourse Modification	$5,796,679	$5,796,679
Commuter Terminal Mods	$2,065,432	N/A
Fuel Farm Modification	$165,575	N/A
Systems Installation	$1,025,000	$782,000
Subtotal	$9,302,685	$6,828,679
Recurring Costs		
Washing Nitrogen	$3,391,151	$1,515,014
Scrubbing Nitrogen	$3,764,616	N/A
Washing Labor	$10,513,190	$4,678,370
Related Maintenance	$657,000	$328,500
Subtotal	$18,325,957	$6,521,884
Totals	$27,628,642	$13,350,562

TABLE 19. SUMMARY OF GBI COST FOR ACY

	Full GBI	Washing HCWTs Only
Nonrecurring Costs		
Engineering/Architectural	$25,000	$25,000
Concourse Modification	$90,859	$90,859
Fuel Truck Modification	$155,000	N/A
Systems Installation	$76,683	$37,282
Subtotal	$347,542	$153,141
Recurring Costs		
Washing Nitrogen	$145,342	$43,875
Scrubbing Nitrogen	$35,309	N/A
Washing Labor	$2,936,660	$334,779
Related Maintenance	$26,280	$13,140
Subtotal	$3,143,591	$391,794
Totals	$3,491,133	$544,936

4.1 ATLANTA HARTSFIELD INTERNATIONAL AIRPORT.

4.1.1 ATL GBI Nonrecurring Cost.

The nonrecurring costs for ATL were broken down into three main categories: engineering/ architecture costs, related equipment and installation costs, and nitrogen generation system installation costs.

An airport architectural firm familiar with the airport estimated the engineering and architecture costs. This includes the cost of modifying the airport electrical, mechanical, and pneumatic plans, as well as any engineering costs associated with that. The estimated total cost was $250,000.

The cost of installing all related plumbing, mechanical, and electrical was estimated by an airport general contractor associated with ATL. Certain specialty items were estimated by vendors for the analysis team and provided to the general contractor. The cost includes the cost of materials, labor, rental equipment, cleanup, fees, and overhead. The cost of modifying the commuter terminal to allow for commuter ullage washing was calculated separately. This is primarily because it is a detailed and specific job with some specialized equipment and skills needed. Also, this cost was separated because it was specific to commuter ullage washing, which could be eliminated for the case of ullage washing HCWTs only. The cost of modifying the ATL fuel farm to provide fuel scrubbing was also calculated separately and was approximately $166,000. The total cost of modifying all concourses and terminals for ullage washing was estimated at $7,862,111 with the cost of modifying the commuter terminal being over 25 percent of that. A complete breakout of costs constituting the airport modification for GBI is given in appendix E.

A large gas supplier that manufactures, leases, and installs HFM nitrogen generators provided the cost of installing the nitrogen generators. The estimated total cost of installing the ullage

washing gas generators at ATL was $782,000, as opposed to $243,000 for the fuel scrubber nitrogen generator, for a total system installation cost of $1,025,000.

4.1.2 ATL GBI Recurring Cost.

The recurring costs for ATL consist of the volume cost of nitrogen, the cost of labor to perform ullage washing for each departure, and the cost of maintenance and repair of the related ullage washing equipment. All nitrogen generation systems have no associated maintenance costs because the volume cost of nitrogen takes into account a service contract.

The volume cost of nitrogen for ATL was applied to the total yearly volume of nitrogen required for both ullage washing and fuel scrubbing obtained in tables 10 and 14. The volume cost of nitrogen was determined by a gas manufacturer to be $0.10 per 100 cubic feet for ullage washing and $0.24 per 100 cubic feet for fuel scrubbing based on the volume requirements and generation systems specified at ATL. The total cost of ullage-washing and fuel-scrubbing nitrogen for the 10-year study at ATL is approximately $3.4 million and $3.8 million respectively. The cost of nitrogen for ullage washing HCWT departures only was calculated to be $1.5 million from the calculated nitrogen volumes in table 14. Table 20 gives a yearly cost breakdown based on total nitrogen volume for ullage washing and fuel scrubbing at ATL for the 10-year study period. Table 21 gives the yearly cost breakdown for ullage washing HCWT departures only.

The cost of labor for providing ullage washing for all departing flights was calculated by having a major operator at ATL determine the total annual cost of providing this service for its fleet. This was done by determining the total cost of personnel (salary and overhead) to the company, given each departure requires 10 minutes of labor. The total cost of labor to the company was calculated using existing company standards for hiring labor to perform task work. This cost was then divided by the airlines projected yearly departures to obtain a cost per departure. This cost was then multiplied by the FAA APO annual departure data for ATL to obtain a yearly cost for each year in the study. The total labor cost calculated for ATL for all departures is $10.5 million, with a cost of $4.7 million for ullage washing HCWT departures only. The labor costs are tabulated on a yearly basis in tables 20 and 21.

TABLE 20. RECURRING COSTS BASED ON ALL DEPARTURES FOR ATL

Year	Total Departures	Washing N_2 Volume	Scrubbing N_2 Volume	Washing N_2 Cost	Scrubbing N_2 Cost	Washing Labor
2003	419,202	301,537,113	139,477,170	$301,537	$334,745	$934,820
2004	430,811	309,887,608	143,339,725	$309,888	$344,015	$960,709
2005	442,420	318,238,104	147,202,279	$318,238	$353,285	$986,597
2006	454,030	326,589,318	151,065,166	$326,589	$362,556	$1,012,487
2007	465,639	334,939,813	154,927,720	$334,940	$371,827	$1,038,375
2008	477,248	343,290,309	158,790,274	$343,290	$381,097	$1,064,263
2009	488,858	351,641,523	162,653,161	$351,642	$390,368	$1,090,153
2010	500,466	359,991,299	166,515,383	$359,991	$399,637	$1,116,039
2011	512,076	368,342,514	170,378,270	$368,343	$408,908	$1,141,929
2012	523,685	376,693,009	174,240,824	$376,693	$418,178	$1,167,818
Totals	4,714,435	3,391,150,612	1,568,589,972	$3,391,151	$3,764,616	$10,513,190

TABLE 21. RECURRING COSTS BASED ON HCWT DEPARTURES FOR ATL

Year	HCWT Departures	Washing N_2 Volume	Washing N_2 Cost	Washing Labor
2003	186,545	134,713,292	$134,713	$415,995
2004	191,711	138,443,919	$138,444	$427,515
2005	196,877	142,174,547	$142,175	$439,035
2006	202,043	145,905,496	$145,905	$450,557
2007	207,209	149,636,124	$149,636	$462,077
2008	212,375	153,366,752	$153,367	$473,597
2009	217,542	157,097,701	$157,098	$485,118
2010	222,707	160,828,007	$160,828	$496,637
2011	227,874	164,558,956	$164,559	$508,159
2012	233,040	168,289,584	$168,290	$519,679
Totals	2,097,924	1,515,014,378	$1,515,014	$4,678,370

The cost of maintenance of the related ullage-washing equipment was estimated at $65,700 per year. This was estimated based on the number of gates at ATL and the estimated amount of maintenance needed at a gate on an annual basis. For HCWT departures only, maintenance was assumed to be half as much. Although the same basic amount of equipment is utilized in both systems, the usage is approximately half, which can be estimated as half the maintenance cost. Fuel-scrubbing maintenance and repair is virtually zero as a fuel scrubber has no moving parts, and the nitrogen generator maintenance is included in the volume cost of the gas.

4.2 ATLANTIC CITY INTERNATIONAL AIRPORT.

4.2.1 ACY GBI Nonrecurring Cost.

The nonrecurring costs for ACY were broken down into three main categories. Engineering/ architecture costs, related equipment and installation costs, and nitrogen generation system installation costs.

The engineering and architecture costs were estimated given the cost of the work at ATL. This includes the cost of modifying the airport electrical, mechanical, and pneumatic plans, as well as any engineering costs associated with that. The estimated total cost was $25,000.

An airport contract engineer employed by the South Jersey Transit Authority estimated the cost of performing the necessary plumbing, mechanical, and electrical modifications. Certain specialty items were estimated by vendors for the analysis team and provided to the airport engineer. The cost includes the cost of materials, labor, rental equipment, clean-up, fees and overhead. The cost of modifying the ACY fuel truck with a portable fuel scrubber in tow was also calculated separately and was approximately $155,000. The total cost of modifying all concourses and commuter parking areas was $90,859. A complete breakout of costs constituting the airport modification for GBI is given in appendix F.

A large gas manufacturer that manufactures, leases, and installs HFM nitrogen generators provided the cost of installing the nitrogen generators. The estimated total cost of installing the

ullage-washing gas generator at ACY was $37,282, as opposed to $39,401 for the fuel scrubber nitrogen generator, for a total system installation cost of $76,683.

4.2.2 ACY GBI Recurring Cost.

The recurring costs for ACY consist of the volume cost of nitrogen, the cost of labor to perform ullage washing for each departure, and the cost of maintenance and repair of the related ullage-washing equipment. All nitrogen generation systems have no associated maintenance costs because the volume cost of nitrogen takes into account a service contract.

The volume cost of nitrogen for ACY was applied to the total yearly volume of nitrogen required for both ullage washing and fuel scrubbing obtained in tables 13 and 17. The volume cost of nitrogen was determined by a gas manufacturer to be $0.47 per 100 cubic feet for ullage washing and $0.22 per 100 cubic feet for fuel scrubbing based on the volume requirements and generation systems specified at ACY. The total cost of ullage-washing and fuel-scrubbing nitrogen for the 10-year study at ACY was calculated as $145,342 and $35,309 respectively. The cost of nitrogen for ullage-washing HCWT departures only was calculated to be $43,875 (from table 15). Table 22 gives a yearly cost breakdown based on calculated nitrogen volumes for ullage washing and fuel scrubbing at ACY for the 10-year study period. Table 23 gives the same cost breakdown for ullage washing HCWT departures only.

The cost of labor for providing ullage washing for all departing flights was calculated by having a service provider at ACY determine the approximate cost of providing this service for a customer. The estimate, given a large degree of uncertainty, was $20. This cost was then multiplied by the FAA APO annual departure data for ACY to obtain a yearly cost for each year in the study. The total labor cost for ACY for all departures is approximately $2.9 million, with a cost of approximately $335,000 for ullage washing HCWT departures only. These labor costs are also tabulated on a yearly basis in tables 22 and 23.

TABLE 22. RECURRING COSTS BASED ON ALL DEPARTURES FOR ACY

Year	Total Departures	Washing N_2 Volume	Scrubbing N_2 Volume	Washing N_2 Cost	Scrubbing N_2 Cost	Washing Labor Cost
2003	13,559	2,855,590	1,482,070	$13,421	$3,261	$271,180
2004	13,809	2,908,241	1,509,396	$13,669	$3,321	$276,180
2005	14,058	2,960,681	1,536,613	$13,915	$3,381	$281,160
2006	14,309	3,013,543	1,564,049	$14,164	$3,441	$286,180
2007	14,558	3,065,984	1,591,266	$14,410	$3,501	$291,160
2008	14,808	3,118,635	1,618,592	$14,658	$3,561	$296,160
2009	15,058	3,171,286	1,645,919	$14,905	$3,621	$301,160
2010	15,308	3,223,937	1,673,245	$15,153	$3,681	$306,160
2011	15,558	3,276,589	1,700,571	$15,400	$3,741	$311,160
2012	15,808	3,329,240	1,727,898	$15,647	$3,801	$316,160
Totals	146,833	30,923,726	16,049,620	$145,342	$35,309	$2,936,660

TABLE 23. RECURRING COSTS BASED ON HCWT DEPARTURES FOR ACY

Year	HCWT Departures	Washing N_2 Volume	Washing N_2 Cost	Washing Labor Cost
2003	1,546	862,036	$4,052	$30,915
2004	1,574	877,930	$4,126	$31,485
2005	1,603	893,761	$4,201	$32,052
2006	1,631	909,718	$4,276	$32,625
2007	1,660	925,549	$4,350	$33,192
2008	1,688	941,443	$4,425	$33,762
2009	1,717	957,337	$4,499	$34,332
2010	1,745	973,232	$4,574	$34,902
2011	1,774	989,126	$4,649	$35,472
2012	1,802	1,005,020	$4,724	$36,042
Totals	16,739	9,335,152	$43,875	$334,779

The cost of maintenance of the related-ullage washing equipment was estimated at $2,628 per year. This was estimated based on the amount of gates at ACY and the estimated amount of maintenance needed at a gate on an annual basis. For HCWT departures only, maintenance was assumed to be half as much. Although the same basic amount of equipment is utilized in both systems, the usage (based on departures) is approximately half, which can be estimated as half the maintenance cost. Again, fuel-scrubbing maintenance and repair is virtually zero as a fuel scrubber has no moving parts, and the nitrogen generator maintenance is included in the volume cost of the gas.

5. INDUSTRY COST ANALYSIS.

To extrapolate the cost of GBI to all or part of the US air transportation system, the calculated airport recurring and nonrecurring costs were used. It was assumed that the nonrecurring costs of GBI implementation at ATL was representative of the cost of implementation at a typical large airport, and GBI nonrecurring costs at ACY were typical of a small airport. It was also assumed that the volume cost of nitrogen for ullage washing and fuel scrubbing at ATL was consistent with a volume cost at a typical large airport, and nitrogen costs at ACY were typical of a small airport.

DOT T3 data was used to determine the industry departure averages in terms of aircraft category (single aisle, wide body, and commuter) as well as percentage of passenger departures, and percentage of large airport departures. FAA APO forecast data was utilized for the time period 2003-2012 to determine the number of flights departing from US airports within the study period.

ATL and ACY nonrecurring costs were scaled with the number of U.S. airports and ATL and ACY calculated nitrogen requirements by departure were utilized to determine the industry recurring costs. Table 24 gives a summary of the costs associated with GBI for all US departures. The following sections describe the methods for determining the costs associated with each cost category.

TABLE 24. SUMMARY OF INDUSTRY GBI COST

	Full GBI	Washing HCWTs Only
Nonrecurring Costs		
Large Airport Concourse Modification	$341,433,925	$341,433,925
Large Airport Commuter Modification	$103,271,575	N/A
Large Airport Fuel Farm Modification	$20,428,750	N/A
Small Airport Concourse Modification	$53,599,438	$53,599,438
Small Airport Fuel Truck Modification	$68,040,350	N/A
Subtotal	$586,774,038	$395,033,363
Recurring Costs		
Large Airport Washing Nitrogen	$67,210,173	$41,280,008
Large Airport Scrubbing Nitrogen	$73,510,254	N/A
Large Airport Washing Labor	$250,025,528	$133,816,480
Large Airport Related Maintenance	$32,850,000	$16,425,000
Small Airport Washing Nitrogen	$64,721,179	$39,896,322
Small Airport Scrubbing Nitrogen	$16,309,117	N/A
Small Airport Washing Labor	$457,951,135	$157,914,185
Small Airport Related Maintenance	$9,198,000	$4,599,000
Subtotal	$971,775,387	$393,930,994
Totals	$1,558,549,424	$788,964,357

5.1 INDUSTRY NONRECURRING COST.

After review of Air Transport Association (ATA) data, it was determined that of the 418 primary US airports, approximately 400 airports fall into the category of "regularly" departing a commercial transport airplane with 19 seats or greater. Reviewing the properties of the larger of these airports, the assumption was made that the largest 50 of these airports fall into the "large" category, and therefore, the smallest 350 could be labeled "small." Appendix G gives a list of airports that were categorized as large for the sake of the cost analysis. The airport designators for the remaining 350 categorized as small are also given in Appendix G.

5.1.1 Ullage Washing Cost.

To determine the cost of modifying all requisite large US airport concourses with nitrogen systems, the cost of modifying ATL was simply multiplied by 50 (50 airports considered large). In a similar manner, the cost of modifying all small airports with ullage-washing capability was determined by multiplying the cost of modifying ACY by 350. The same modification cost was assumed for concourse modifications required to ullage wash HCWT departures.

To determine the cost of modifying the commuter terminal of all large US airports with nitrogen systems, the cost of modifying the ATL commuter terminal was simply multiplied by 50. This assumes that all airports considered large for this study have a large commuter parking area that would require extensive modification to allow for convenient ullage washing of commuter

departures. No cost of modification was considered for the case of HCWT departures only as it was assumed that only Boeing (exclusive of former McDonnell Douglas aircraft) and Airbus airplanes had heated center wing fuel tanks.

5.1.2 Fuel Scrubbing Cost.

To determine the cost of modifying all requisite large US airport fuel farms with fuel-scrubbing systems, the cost of modifying the ATL fuel farm was simply multiplied by 50. In a similar manner, the cost of modifying all small airport fuel trucks was determined by multiplying the cost of modifying ACY by 350. Again, it was assumed that HCWT departures would not facilitate fuel scrubbing.

5.2 INDUSTRY RECURRING COST.

To determine the total recurring cost of GBI, the FAA APO forecast data had to be manipulated to obtain a number of total departures applicable to the GBI study. The study considers all passenger flights of airplanes with more than 19 seats. Separately, the study also considers only airplanes with heated center wing tanks.

The two categories of APO forecasting relevant to the above stated representative departures are Commercial Air movements, and Commuter/Air Taxi movements. To obtain an estimated amount of relevant departures, it was assumed that 20% of Commuter/Air Taxi movements were aircraft with less then 19 seats. Departures are traditionally obtained by dividing movements by two.

$$\text{Total Applicable Departures} = \frac{(\text{Com Air} + \text{AT and Comm}) - 0.2 * \text{AT and Comm}}{2}$$

Table 25 gives 2003-2012 APO forecasts and the resulting estimated departures.

TABLE 25. ESTIMATED RELEVANT DEPARTURE DATA FROM 2003-2012 APO FORECASTS

Year	Projected Air Carrier	Projected AT & Comm.	Estimated Departures
2003	16,378,133	15,444,302	14,366,787
2004	16,786,911	15,692,037	14,670,270
2005	17,204,670	15,935,368	14,976,482
2006	17,647,592	16,168,052	15,291,017
2007	18,099,587	16,396,966	15,608,580
2008	18,561,022	16,622,531	15,929,523
2009	19,027,702	16,884,554	16,267,673
2010	19,502,961	17,144,882	16,609,433
2011	19,957,826	17,386,781	16,933,625
2012	20,420,250	17,626,671	17,260,793
		Total	157,914,185

To determine how these estimated total departures should be applied to the study, DOT T3 data were obtained. This data categorizes all US aircraft departures, with greater than 60-passenger capability, in terms of flight type, aircraft model, and airport departing. Separating this data in terms of the 50 large airports considered in the study and all small airport data allowed for the calculation of departure percentages in terms of passenger (as opposed to cargo), HCWT, and aircraft category. Table 26 summarizes the percentages calculated from the DOT T3 scheduled and unscheduled data. These percentages were applied to the relevant APO departure data in table 25 to obtain the amount of wide-body, single aisle, and commuter departures predicted on a yearly basis for the complete GBI cost and washing HCWT departures only cost. Although a large percentage of departures tracked by the FAA in air taxi/commuter category (30-40%) are not considered in the T3 data, it can be assumed that this bias would increase the amount of nitrogen predicted. This is due to the fact that the error would tend to bias the single aisle and wide-body departure percentages high, as the vast majority of departures not considered are commuter type departures.

TABLE 26. CALCULATED RELEVANT US DEPARTURE PERCENTAGES BY AIRCRAFT CATEGORY

	Percentage of Relevant Departures			
	All Departures		HCWT Only	
	Large Airports	Small Airports	Large Airports	Small Airports
Applicable GBI Departures	67%	24%	38%	10%
Single Aisle	80%	62%	94%	89%
Wide Body	6%	6%	6%	11%
Commuter	14%	32%	0%	0%
Totals	100%	100%	100%	100%

5.2.1 Ullage-Washing Nitrogen Cost.

The cost of ullage-washing nitrogen for all applicable departures at large airports was determined using the above calculated percentages of relevant US departures for large airports (see table 26) on the relevant departure data in table 25 for each year. These departure totals were then multiplied by the calculated nitrogen requirements for ullage washing for each aircraft category given in table 8. These subtotals were then added to obtain total nitrogen required on a yearly basis. This volume of nitrogen required was then multiplied by the volume cost of nitrogen for ullage washing at ATL to obtain a total cost of nitrogen for ullage washing at large airports on a yearly basis. These yearly costs were then summed for the 10-year study period to obtain a total cost of nitrogen for ullage washing at large airports. This calculation method was performed separately for complete full GBI on all applicable departures (table 27) and also for HCWT departures only (table 28).

The total cost of ullage washing nitrogen for small airports was calculated in a similar manner with the small airport percentages used on the data in table 25 data with ullage washing nitrogen requirements from table 9. The total calculated volume of nitrogen was then multiplied by the volume cost of ullage washing nitrogen at ACY on a yearly basis to obtain a yearly cost of ullage washing nitrogen for each year in the 10-year study period. Again, this calculation method was performed separately for complete full GBI on all applicable departures (table 29) and also for HCWT departures only (table 30).

TABLE 27. LARGE AIRPORT ULLAGE-WASHING NITROGEN COST FOR GBI ALL APPLICABLE DEPARTURES

Year	Large Airport Departures				Nitrogen Volume (cubic feet)				Total N_2 Cost*
	Total US Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N_2 Volume	
2003	14,366,787	577,545	7,700,598	1,347,605	1,145,964,490	4,652,008,253	307,078,671	6,114,677,163	$6,114,677
2004	14,670,270	589,745	7,863,265	1,376,071	1,170,171,763	4,750,276,947	313,565,379	6,243,843,171	$6,243,843
2005	14,976,482	602,055	8,027,394	1,404,794	1,194,596,706	4,849,429,267	320,110,416	6,374,170,632	$6,374,171
2006	15,291,017	614,699	8,195,985	1,434,297	1,219,685,508	4,951,276,501	326,833,343	6,508,040,334	$6,508,040
2007	15,608,580	627,465	8,366,199	1,464,085	1,245,015,878	5,054,104,373	333,621,002	6,643,199,002	$6,643,199
2008	15,929,523	640,367	8,538,225	1,494,189	1,270,615,885	5,158,026,828	340,480,915	6,779,796,409	$6,779,796
2009	16,267,673	653,960	8,719,473	1,525,908	1,297,588,302	5,267,520,540	347,708,585	6,923,716,768	$6,923,717
2010	16,609,433	667,699	8,902,656	1,557,965	1,324,848,790	5,378,183,666	355,013,449	7,069,174,225	$7,069,174
2011	16,933,625	680,732	9,076,423	1,588,374	1,350,707,921	5,483,158,028	361,942,798	7,207,154,275	$7,207,154
2012	17,260,793	693,884	9,251,785	1,619,062	1,376,804,424	5,589,095,995	368,935,754	7,346,400,904	$7,346,401
Totals	157,914,185	6,348,150	84,642,003	14,812,351	12,595,999,668	51,133,080,399	3,375,290,312	67,210,172,883	$67,210,173

* Uses $0.10 per 100 cubic feet of nitrogen

TABLE 28. LARGE AIRPORT ULLAGE-WASHING NITROGEN COST FOR HCWT DEPARTURES ONLY

Year	Large Airport HCWT Departures				Nitrogen Volume (cubic feet)				Total N_2 Cost*
	Total US Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N_2 Volume	
2003	14,366,787	327,563	5,131,816	0	649,950,009	3,100,181,620	0	3,755,591,008	$3,755,591
2004	14,670,270	334,482	5,240,221	0	663,679,508	3,165,669,637	0	3,834,923,847	$3,834,924
2005	14,976,482	341,464	5,349,599	0	677,532,460	3,231,746,519	0	3,914,970,042	$3,914,970
2006	15,291,017	348,635	5,461,951	0	691,761,930	3,299,619,340	0	3,997,191,857	$3,997,192
2007	15,608,580	355,876	5,575,385	0	706,128,409	3,368,145,675	0	4,080,205,344	$4,080,205
2008	15,929,523	363,193	5,690,026	0	720,647,816	3,437,401,461	0	4,164,102,495	$4,164,102
2009	16,267,673	370,903	5,810,813	0	735,945,604	3,510,370,032	0	4,252,497,351	$4,252,497
2010	16,609,433	378,695	5,932,890	0	751,406,776	3,584,117,921	0	4,341,836,282	$4,341,836
2011	16,933,625	386,087	6,048,691	0	766,073,149	3,654,074,716	0	4,426,582,642	$4,426,583
2012	17,260,793	393,546	6,165,555	0	780,874,151	3,724,673,674	0	4,512,106,927	$4,512,107
Totals	157,914,185	3,600,443	56,406,947	0	7,143,999,812	34,076,000,595	0	41,280,007,797	$41,280,008

* Uses $0.10 per 100 cubic feet of nitrogen

TABLE 29. SMALL AIRPORT ULLAGE-WASHING NITROGEN COST FOR GBI ALL APPLICABLE DEPARTURES

	Small Airport Departures				Nitrogen Volume (cubic feet)				
Year	Total US Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N_2 Volume	Total N_2 Cost*
2003	14,366,787	206,882	2,137,778	1,103,369	410,494,743	764,512,151	74,360,468	1,252,815,391	$5,888,232
2004	14,670,270	211,252	2,182,936	1,126,677	419,166,005	780,661,651	75,931,253	1,279,279,774	$6,012,615
2005	14,976,482	215,661	2,228,501	1,150,194	427,915,238	796,956,367	77,516,163	1,305,982,124	$6,138,116
2006	15,291,017	220,191	2,275,303	1,174,350	436,902,272	813,693,966	79,144,150	1,333,410,232	$6,267,028
2007	15,608,580	224,764	2,322,557	1,198,739	445,975,837	830,592,723	80,787,812	1,361,102,431	$6,397,181
2008	15,929,523	229,385	2,370,313	1,223,387	455,145,989	847,671,364	82,448,970	1,389,089,409	$6,528,720
2009	16,267,673	234,254	2,420,630	1,249,357	464,807,750	865,665,587	84,199,183	1,418,576,762	$6,667,311
2010	16,609,433	239,176	2,471,484	1,275,604	474,572,701	883,851,992	85,968,088	1,448,379,045	$6,807,382
2011	16,933,625	243,844	2,519,723	1,300,502	483,835,673	901,103,504	87,646,061	1,476,649,308	$6,940,252
2012	17,260,793	248,555	2,568,406	1,325,629	493,183,674	918,513,374	89,339,436	1,505,179,075	$7,074,342
Totals	157,914,185	2,273,964	23,497,631	12,127,809	4,511,999,881	8,403,222,680	817,341,585	13,770,463,550	$64,721,179

* Uses $0.47 per 100 cubic feet of nitrogen

TABLE 30. SMALL AIRPORTS ULLAGE-WASHING NITROGEN COSTS FOR HCWT DEPARTURES ONLY

	Small Airport HCWT Departures				Nitrogen Volume (cubic feet)				
Year	Total US Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N_2 Volume	Total N_2 Cost*
2003	14,366,787	158,035	1,278,644	0	313,572,373	457,268,692	0	772,277,744	$3,629,705
2004	14,670,270	161,373	1,305,654	0	320,196,254	466,928,004	0	788,591,284	$3,706,379
2005	14,976,482	164,741	1,332,907	0	326,879,696	476,674,171	0	805,051,515	$3,783,742
2006	15,291,017	168,201	1,360,900	0	333,744,791	486,685,235	0	821,959,128	$3,863,208
2007	15,608,580	171,694	1,389,164	0	340,675,987	496,792,691	0	839,029,535	$3,943,439
2008	15,929,523	175,225	1,417,728	0	347,680,964	507,007,738	0	856,281,654	$4,024,524
2009	16,267,673	178,944	1,447,823	0	355,061,476	517,770,412	0	874,458,655	$4,109,956
2010	16,609,433	182,704	1,478,240	0	362,520,813	528,648,033	0	892,829,789	$4,196,300
2011	16,933,625	186,270	1,507,093	0	369,596,695	538,966,477	0	910,256,535	$4,278,206
2012	17,260,793	189,869	1,536,211	0	376,737,529	549,379,639	0	927,843,248	$4,360,863
Totals	157,914,185	1,737,056	14,054,362	0	3,446,666,576	5,026,121,092	0	8,488,579,086	$39,896,322

* Uses $0.47 per 100 cubic feet of nitrogen

5.2.2 Fuel-Scrubbing Nitrogen Cost.

The cost of fuel-scrubbing nitrogen for all applicable departures at large airports was calculated using the above calculated percentages of relevant US departures for large airports (see table 26) on the relevant departure data in table 25 for each year. These departure totals were then multiplied by the calculated nitrogen requirements for fuel scrubbing for each aircraft category given in table 8. These subtotals were then added to obtain total nitrogen required on a yearly basis. This volume of nitrogen required was then multiplied by the volume cost of nitrogen for fuel scrubbing at ATL to obtain a total cost of nitrogen for fuel scrubbing at large airports on a yearly basis. These yearly costs were then summed for the 10-year study period to obtain a total cost of nitrogen for fuel scrubbing (table 31).

The total cost of fuel scrubbing for small airports was calculated in a similar manner with the small airport percentages used on table 25 data with fuel-scrubbing nitrogen requirements from table 9. The total calculated volume of nitrogen was then multiplied by the volume cost of fuel-scrubbing nitrogen at ACY on a yearly basis to obtain a yearly cost of fuel-scrubbing nitrogen for each year in the 10-year study period (table 32).

5.2.3 Ullage-Washing Labor Cost.

To determine the cost of labor for all applicable departures at large airports the percentages calculated in table 26 were applied to the relevant departures in table 25 to obtain the total amount of departures from large airports on a yearly basis for the 10-year study period 2003-2012. This number was then multiplied by the calculated ATL labor cost per departure ($2.23) to obtain the total cost of labor for ullage washing at large airports for all applicable GBI departures. This process was repeated for HCWT departures only using the HCWT washing percentages in table 26. Table 33 gives the labor costs of all relevant departures and HCWT departures for large airports for the specified 10-year study period.

To determine cost of labor for all applicable departures at small airports, the percentages calculated in table 26 were applied to the relevant departures in table 25 to obtain the total amount of departures from small airports on a yearly basis for the 10-year study period 2003-2012. Although the cost per departure at ACY was $20, discussions with another small airport service provider gave a price of zero dollars, depending upon service competition, with both prices having a high degree of uncertainty. The two estimates were averaged giving $10 per departure. This is consistent with the belief that small airport costs associated with GBI will be highly location, operator, and season dependant, particularly with respect to labor. Table 34 gives the labor costs of all relevant departures and HCWT departures for small airports for the specified 10-year study period.

5.2.4 Annual Maintenance Cost.

Annual cost of maintenance for the ancillary and related equipment for GBI was calculated using the approximations determined for ATL and ACY. The annual cost of maintenance at large airports was calculated by multiplying the cost of annual maintenance at ATL by 50. Similarly, the annual cost of maintenance at small airports was calculated by multiplying the cost of annual maintenance at ACY by 350. These maintenance costs assume that all maintenance related to

TABLE 31. LARGE AIRPORT FUEL-SCRUBBING NITROGEN COST FOR GBI ALL APPLICABLE DEPARTURES

Year	Large Airport Departures				Nitrogen Volume (cubic feet)				Total N_2 Cost*
	Total US Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N_2 Volume	
2003	14,366,787	577,545	7,700,598	1,347,605	578,411,167	2,122,515,825	85,676,661	2,786,603,652	$6,687,849
2004	14,670,270	589,745	7,863,265	1,376,071	590,629,483	2,167,351,699	87,486,488	2,845,467,671	$6,829,122
2005	14,976,482	602,055	8,027,394	1,404,794	602,957,666	2,212,590,735	89,312,590	2,904,860,991	$6,971,666
2006	15,291,017	614,699	8,195,985	1,434,297	615,620,924	2,259,059,347	91,188,324	2,965,868,595	$7,118,085
2007	15,608,580	627,465	8,366,199	1,464,085	628,406,109	2,305,975,383	93,082,119	3,027,463,611	$7,265,913
2008	15,929,523	640,367	8,538,225	1,494,189	641,327,391	2,353,390,831	94,996,073	3,089,714,294	$7,415,314
2009	16,267,673	653,960	8,719,473	1,525,908	654,941,379	2,403,348,209	97,012,633	3,155,302,221	$7,572,725
2010	16,609,433	667,699	8,902,656	1,557,965	668,700,767	2,453,839,142	99,050,731	3,221,590,640	$7,731,818
2011	16,933,625	680,732	9,076,423	1,588,374	681,752,839	2,501,734,531	100,984,058	3,284,471,427	$7,882,731
2012	17,260,793	693,884	9,251,785	1,619,062	694,924,721	2,550,069,572	102,935,132	3,347,929,424	$8,035,031
Totals	157,914,185	6,348,150	84,642,003	14,812,351	6,357,672,446	23,329,875,272	941,724,809	30,629,272,527	$73,510,254

* Uses $0.24 per 100 cubic feet of nitrogen

TABLE 32. SMALL AIRPORT FUEL-SCRUBBING NITROGEN COST FOR GBI ALL APPLICABLE DEPARTURES

Year	Small Airport Departures				Nitrogen Volume (cubic feet)				Total N_2 Cost*
	Total US Departures	Wide Body	Single Aisle	Commuter	Wide Body	Single Aisle	Commuter	Total N_2 Volume	
2003	14,366,787	206,882	2,137,778	1,103,369	207,192,060	457,783,770	9,468,784	674,444,614	$1,483,778
2004	14,670,270	211,252	2,182,936	1,126,677	211,568,770	467,453,962	9,668,802	688,691,534	$1,515,121
2005	14,976,482	215,661	2,228,501	1,150,194	215,984,836	477,211,108	9,870,618	703,066,562	$1,546,746
2006	15,291,017	220,191	2,275,303	1,174,350	220,520,928	487,233,449	10,077,920	717,832,297	$1,579,231
2007	15,608,580	224,764	2,322,557	1,198,739	225,100,696	497,352,289	10,287,218	732,740,203	$1,612,028
2008	15,929,523	229,385	2,370,313	1,223,387	229,729,215	507,578,843	10,498,744	747,806,802	$1,645,175
2009	16,267,673	234,254	2,420,630	1,249,357	234,605,867	518,353,640	10,721,609	763,681,117	$1,680,098
2010	16,609,433	239,176	2,471,484	1,275,604	239,534,603	529,243,514	10,946,855	779,724,972	$1,715,395
2011	16,933,625	243,844	2,519,723	1,300,502	244,209,972	539,573,582	11,160,522	794,944,075	$1,748,877
2012	17,260,793	248,555	2,568,406	1,325,629	248,928,258	549,998,473	11,376,150	810,302,881	$1,782,666
Totals	157,914,185	2,273,964	23,497,631	12,127,809	2,277,375,205	5,031,782,631	104,077,222	7,413,235,058	$16,309,117

* Uses $0.22 per 100 cubic feet of nitrogen

TABLE 33. LARGE AIRPORT LABOR COST

Year	Total US Departures	All Applicable Departures	All Applicable Labor Cost	Only HCWT Departures	Only HCWT Labor Cost
2003	14,366,787	10,200,419	$22,746,934	5,459,379	$12,174,416
2004	14,670,270	10,415,892	$23,227,439	5,574,703	$12,431,587
2005	14,976,482	10,633,302	$23,712,264	5,691,063	$12,691,071
2006	15,291,017	10,856,622	$24,210,267	5,810,586	$12,957,608
2007	15,608,580	11,082,092	$24,713,065	5,931,260	$13,226,711
2008	15,929,523	11,309,962	$25,221,214	6,053,219	$13,498,678
2009	16,267,673	11,550,048	$25,756,606	6,181,716	$13,785,226
2010	16,609,433	11,792,698	$26,297,716	6,311,585	$14,074,834
2011	16,933,625	12,022,874	$26,811,009	6,434,778	$14,349,554
2012	17,260,793	12,255,163	$27,329,014	6,559,101	$14,626,796
Totals	157,914,185	112,119,071	$250,025,528	60,007,390	$133,816,480

* Uses $2.23 labor cost per departure

TABLE 34. SMALL AIRPORT LABOR COST

Year	Total US Departures	Applicable Departures	Labor Cost	Only HCWT Departures	Only HCWT Labor Cost
2003	14,366,787	4,166,368	$41,663,683	1,436,679	$14,366,787
2004	14,670,270	4,254,378	$42,543,784	1,467,027	$14,670,270
2005	14,976,482	4,343,180	$43,431,798	1,497,648	$14,976,482
2006	15,291,017	4,434,395	$44,343,949	1,529,102	$15,291,017
2007	15,608,580	4,526,488	$45,264,882	1,560,858	$15,608,580
2008	15,929,523	4,619,562	$46,195,618	1,592,952	$15,929,523
2009	16,267,673	4,717,625	$47,176,251	1,626,767	$16,267,673
2010	16,609,433	4,816,736	$48,167,357	1,660,943	$16,609,433
2011	16,933,625	4,910,751	$49,107,514	1,693,363	$16,933,625
2012	17,260,793	5,005,630	$50,056,301	1,726,079	$17,260,793
Totals	157,914,185	45,795,114	$457,951,135	15,791,418	$157,914,185

* Uses $10 labor cost per departure

the nitrogen generation systems is part of the lease gas costs and that all fuel-scrubbing equipment has essentially zero maintenance costs.

6. CONCLUSIONS AND RECOMMENDATIONS.

Recent studies have indicated that fuel tank inerting could allow for a significant increase in the safety of fuel tanks in the existing fleet [1,3]. Ground-based inerting of fuel tanks offers a significant cost advantage over other fuel tank inerting methods in that it has a very small impact on the commercial transport airplane fleet, while providing a high level of protection to the vast majority of flight profiles. The installation of nitrogen generation systems at airports could provide a cost benefit to some airport operations. Tire servicing and produce blanketing could benefit from on site-generated nitrogen and future aircraft protection systems could be provided nitrogen on site at a lower volume cost.

Excluding the cost of aircraft modification, the cost of implementing complete GBI (ullage washing and fuel scrubbing) for the US fleet was calculated at approximately $1.6 billion over the next 13 years, with a 3-year implementation period. To wash the center wing tank ullage of HCWT departures only, the cost would be approximately $800 million for the same time period.

To decrease the amount of uncertainty in the study, further analysis of portable fuel scrubbing would need to be performed to ensure the costs associated with this item would indeed be as predicted in the existing study. Also, a better understanding of small airport fixed base operators and the methods of service provision and cost development could allow a more accurate number for small airport labor costs with less uncertainty. Additional testing of aircraft fuel tanks to determine the duration of the inerting benefit during ground operations and initial flight operations is needed.

In addition to the further evaluation of ground-based inerting, additional evaluation of on-board inerting methods using the latest technology available is needed to compare on-board systems, including those that would be sized to operate on the ground only, to ground-based inerting. The FAA plans to re-task the ARAC to perform a detailed study of airplane fuel tank inerting methods. The data in this report will be provided to this new ARAC working group to be assembled in the year 2000.

7. REFERENCES.

1. Aviation Rulemaking Advisory Committee, "Fuel Tank Harmonization Working Group Final Report," July 1998.

2. "A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks," DOT/FAA/AR-98/26, June 1998.

3. Cherry, R. and Warren, K., "A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion," DOT/FAA/AR-99/73, December 1999.

APPENDIX A—GBI COST ANALYSIS TEAM MEMBERS

The GBI cost analysis team is described in the statement of work as follows:

Member 1. A lead, having a background in aviation fire safety with knowledge in the area of fuel tank inerting. This individual shall have a demonstrated ability to supervise a small group and write technical reports.

Member 2. A member with knowledge of ground inerting systems and their costs.

Member 3. A member representing a major US airport with knowledge of and access to the infrastructure of that airport.

Member 4. A member representing the same airport as above (member 3) with knowledge in the airport side turnaround of aircraft (fueling, baggage, maintenance etc).

Members 5 and 6. Additional members equivalent to member 3 and 4 above with the same qualifications only for a small airport with transport aircraft traffic.

The following people have been selected as team members:

Member 1: William M. Cavage - DOT FAA AAR-422, Fire Safety Researcher
Mr. Cavage is a Research and Systems Engineer with over 7 years experience in aviation safety. He is currently leading the fuel tank inerting research efforts at the FAA Technical Center for AAR-422, Fire Safety Section.

Member 2: Karl Beers - Air Liquide/MEDAL, OBIGGS Engineer
Mr. Beers is Project Manager and New Product Development Director for Air Liquide MEDAL L.P. Air Liquide is the largest gas manufacturer in the world. He is currently leading two projects involving OBIGGS systems on US military projects.

Member 3: Thom Lang - Delta Airlines, Properties and Facilities Manager
Mr. Lang is an architect and is responsible for all aspects of facility construction and modification at Atlanta Hartsfield International Airport (ATL) as it pertains to Delta Airlines. He has 10+ years experience in transportation infrastructure management and modification.

Member 4: Don Thomas - Delta Airlines, Fuel Service Duty Manager
Mr. Thomas is in charge of fueling operations at Atlanta Hartsfield International Airport and has 32 years experience with aircraft servicing. His duties at Delta include refueling process, fuel quality, inventory control, environmental coordinator, and Delta rep for NFPA 407.

Member 5: Pat Northway - SJTA/ACY, Facilities Manager
Pat Northway is the airport manager at Atlantic City International Airport (ACY). He is responsible for all facilities and operations at ACY and has many years experience in airport operations and administration. He is also a commercial pilot.

Member 6: Mike Bent - SJTA/ACY, Operations Manager

Mike Bent is the assistant airport manager at Atlantic City International Airport (ACY). He oversees the daily operations at ACY and has many years experience in civil and military airport operations and FBOs.

APPENDIX B—FUEL SERVICED AND ULLAGE REMAINING CALCULATIONS FOR ATL

TABLE B-1. AVERAGE FUEL ADDED DATA FOR ATLANTA HARTFIELD INTERNATIONAL AIRPORT

Aircraft Type	Number of Departures	Total Fuel Added (gals)	Average Fuel Added (gals)	Average Fuel Added (ft3)
B737	54	84304	1561.185	208.69924
MD88	223	409568	1836.628	245.52040
B757-200	116	366209	3156.974	422.02430
B727S	141	336706	2387.986	319.22594
L-1011	42	304857	7258.500	970.31628
B777	4	14309	3577.250	478.20678
MD11	12	229963	19163.583	2561.78782
B767ER	18	266760	14820.000	1981.13760
B767-2/300	61	299776	4914.361	656.95173
CRJ	95	74000	778.947	104.12968
ATR	47	24500	521.277	69.68426
BAZ	94	23500	250.000	33.42000
Total		2434452		

TABLE B-2. AVERAGE ULLAGE AT DEPARTURE DATA FOR ATLANTA HARTFIELD INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added (gallons)	Average Fuel Existing (gallons)	Average Departure Fuel (gallons)	Average Departure Fuel (cubic feet)	Capacity Fuel Tank (lbs)	Capacity Fuel Tank (cubic feet)	Average Ullage (cubic feet)
B737	1561.185	1725	3286.1852	439.29724	34975	718.7644	279.467203
MD88	1836.628	2400	4236.6278	566.35240	39128	804.1119	237.759531
B757-200	3156.974	2300	5456.9741	729.48830	75391	1549.3458	819.857510
B727S	2387.986	3255	5642.9858	754.35434	54600	1122.0740	367.719662
L-1011	7258.500	5600	12858.5000	1718.92428	132630	2725.6534	1006.729116
B777	3577.250	4500	8077.2500	1079.76678	303034	6227.5929	5147.826156
MD11	19163.583	4750	23913.5833	3196.76782	295997	6082.9769	2886.209095
B767ER	14820.000	3850	18670.0000	2495.80560	161738	3323.8463	828.040656
B767-2/300	4914.361	3850	8764.3607	1171.61973	111900	2299.6352	1128.015456
CRJ	778.947	650	1428.9474	191.02168	21200	435.6771	244.655402
ATR	521.277	300	821.2766	109.78826	11800	242.4995	132.711255
BAZ	250.000	150	400.0000	53.47200	5900	121.2498	67.777755

TABLE B-3. AVERAGE HCWT FUEL ADDED DATA FOR ATLANTA HARTFIELD INTERNATIONAL AIRPORT

Aircraft Type	Number of Flights Examined	Total CWT Fuel Added (gals)	Average CWT Fuel Added (gals)	Average CWT Fuel Added (cubic ft)
B737	10	4236	423.60	56.62685
B757-200	5	4650	930.00	124.32240
B727S	3	5149	1716.33	229.43944
B777	2	3309	1654.50	221.17356
B767ER	3	20000	6666.67	891.20000
B767-2/300	1	2500	2500.00	334.20000

TABLE B-4. AVERAGE HCWT ULLAGE AT DEPARTURE DATA FOR ATLANTA HARTFIELD INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added (gallons)	Average Fuel Existing (gallons)	Average Departure Fuel (gallons)	Average Departure Fuel (cubic feet)	Capacity Fuel Tank (lbs)	Capacity Fuel Tank (cubic feet)	Average Ullage Volume (cubic feet)
B737	423.60	0	423.6000	56.6268	15475.00	318.0237	261.3969
B757-200	930.00	0	930.0000	124.3224	46235.00	950.1665	825.8441
B727S	1716.33	1090	2806.3333	375.1506	30400.00	624.7445	249.5939
B777	1654.50	0	1654.5000	221.1736	174870.00	3593.7194	3372.5459
B767ER	6666.67	0	6666.6667	891.2000	80400.00	1652.2848	761.0848
B767-2/300	2500.00	0	2500.0000	334.2000	30562.00	628.0737	293.8737

TABLE B-5. CALCULATION OF FUEL ADDED AND ULLAGE REMAINING AVERAGES BY AIRCRAFT TYPE FOR ALL DEPARTING AIRCRAFT AT ATLANTA HARTSFIELD INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added at Departure (cubic feet)	Average Ullage Remain at Departure (cubic feet)	Delta/ASA Departure Fraction	Weighted Subtotal Fuel Added (cubic feet)	Weighted Subtotal Ullage Remaining (cubic feet)	
B737	208.699236	279.467203	0.101123596	21.10441708	28.26072842	
MD88	245.520405	237.759531	0.417602996	102.53005663	99.28909267	
B757-200	422.024303	819.857510	0.217228464	91.67569124	178.09638797	**Single**
B727S	319.225944	367.719662	0.264044944	84.28999640	97.09451753	**Aisle**
Totals	1195.469887	1704.803907	1	**299.600**	**402.740**	
L-1011	970.316280	1006.729116	0.306569343	297.46922453	308.63228368	
B777	478.206780	5147.826156	0.029197080	13.96224175	150.30149362	
MD11	2561.787820	2886.209095	0.087591241	224.39017401	252.80663604	**Wide**
B767ER	1981.137600	828.040656	0.131386861	260.29545109	108.79366283	**Body**
B767-2/300	656.951732	1128.015456	0.445255474	292.51135533	502.25505687	
Totals	6648.400212	10996.820479	1	**1088.628**	**1322.789**	
CRJ	104.129684	244.655402	0.402542373	41.91661017	98.48416620	
ATR	69.684255	132.711255	0.199152542	13.87779661	26.42978386	**Commuter**
BAZ	33.420000	67.777755	0.398305085	13.31135593	26.99622454	
Totals	207.233940	445.144413	1	**69.105**	**151.910**	

TABLE B-6. CALCULATION OF FUEL ADDED AND ULLAGE REMAINING AVERAGES BY AIRCRAFT TYPE FOR HCWT DEPARTURES ONLY AT ATLANTA HARTSFIELD INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added at Departure (cubic feet)	Average Ullage Remaining at Departure (cubic feet)	Delta Departure Fraction	Weighted Subtotal Fuel Added (cubic feet)	Weighted Subtotal Ullage Remaining (cubic feet)	
B737	56.626848	261.396874	0.173633441	9.83231444	45.38723864	
B757-200	124.322400	825.844114	0.372990354	46.37105595	308.03188819	**Single**
B727S	229.439440	249.593861	0.453376206	104.02238277	113.15991791	**Aisle**
Totals	410.388688	1336.834850	1	**160.225**	**466.579**	
B777	221.173560	3372.545880	0.048192771	10.65896675	162.53233157	
B767ER	891.200000	761.084800	0.216867470	193.27228916	165.05453494	**Wide**
B767-2/300	334.200000	293.873732	0.734939759	245.61686747	215.97948983	**Body**
Totals	1446.573560	4427.504412	1	**449.548**	**543.566**	

APPENDIX C—FUEL SERVICED AND ULLAGE REMAINING CALCULATIONS FOR ACY

TABLE C-1. AVERAGE FUEL ADDED DATA FOR ATLANTIC CITY INTERNATIONAL AIRPORT

Aircraft Type	Number of Departures	Total Fuel Added (gals)	Average Fuel Added (gals)	Average Fuel Added (ft^3)
B737	2	3600	1800.000	240.62400
DC-9	10	16000	1600.000	213.88800
MD-80	3	5000	1666.667	222.80000
B727	2	5000	2500.000	334.20000
B-1900	12	90	7.500	1.00260
Jetstream 31	3	466	155.333	20.76496
Metro 4	3	700	233.333	31.19200
Total		30156		

TABLE C-2. AVERAGE ULLAGE AT DEPARTURE DATA FOR ATLANTA HARTFIELD INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added (gallons)	Average Fuel Existing (gallons)	Average Departure Fuel (gallons)	Average Departure Fuel (cubic feet)	Capacity Fuel Tank (lbs)	Capacity Fuel Tank (cubic feet)	Average Ullage Volume (cubic feet)
B737	1800.00	800	2600.00	347.5680	34975	718.7644	371.196439
DC-9	1600.00	400	2000.00	267.3600	18532	380.8475	113.487536
MD80	1666.67	500	2166.67	289.6400	32500	667.9012	378.261194
B727	2500.00	2000	4500.00	601.5600	54600	1122.0740	520.514006
B-1900	7.50	300	307.50	41.1066	4469	91.8416	50.734952
Jetstream 31	155.33	100	255.33	34.1330	3042	62.5156	28.382592
Metro 4	233.33	150	383.33	51.2440	4355	89.4988	38.254760

TABLE C-3. CALCULATION OF FUEL ADDED AND ULLAGE REMAINING AVERAGES BY AIRCRAFT TYPE FOR ALL DEPARTING AIRCRAFT AT ATLANTIC CITY INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added at Departure (cubic feet)	Average Ullage Remaining at Departure (cubic feet)	Departure Fraction	Weighted Subtotal Fuel Added (cubic feet)	Weighted Subtotal Ullage Remaining (cubic feet)	
B737	240.624	371.1964388	0.11764706	28.30870588	43.67016927	
DC9	213.888	113.4875362	0.58823529	125.81647059	66.75737426	
MD80	222.8	378.261194	0.17647059	39.31764706	66.75197542	**Single Aisle**
B727	334.2	520.514006	0.11764706	39.31764706	61.23694188	
Totals	1011.512	1383.459175	1	**232.760**	**238.416**	
B-1900	1.0026	50.73495188	0.66666667	0.66840000	33.82330125	
Jetstream 31	20.76	28.38259176	0.16666667	3.46082667	4.73043196	**Commuter**
Metro 4	31.192	38.25476	0.16666667	5.19866667	6.37579333	
Totals	52.95956	117.3723036	1	**9.327**	**44.929**	

TABLE C-4. CALCULATION OF FUEL ADDED AND ULLAGE REMAINING AVERAGES BY AIRCRAFT TYPE HCWT DEPARTURES ONLY AT ATLANTIC CITY INTERNATIONAL AIRPORT

Aircraft Type	Average Fuel Added at Departure (cubic feet)	Average Ullage Remaining at Departure (cubic feet)	Departure Fraction	Weighted Subtotal Fuel Added (cubic feet)	Weighted Subtotal Ullage Remaining (cubic feet)
B737	0.00	318.0237224	0.5	0.0000	159.0118612
B727	200.52	424.2245015	0.5	100.2600	212.1122507
Totals	200.52	742.2482239	1.0	**100.260**	**371.124**

APPENDIX D—DETAILED AIRPORT NEA SYSTEMS ARCHITECTURE

Part I—Large Airport – Based on Atlanta Hartsfield Airport

There are two types of equipment required to support ground-based inerting (GBI) of commercial aircraft. One type of equipment is designed to completely serve the nitrogen enriched air (NEA) requirements for the Atlanta Hartsfield Airport (ATL) for ullage washing all of the required aircraft prior to departure. This equipment configuration is based on a separate nitrogen generator at each airport concourse. The generators are set up to supply 95% NEA and are interconnected with all of the other concourse nitrogen generators to provide redundancy and insure 100% equipment up time. The system includes a distribution system, which will allow nitrogen to be provided to the individual aircraft and dispensed at each airport gate.

The other type of nitrogen system required at the large airport is for fuel scrubbing. This nitrogen generation equipment is similar in design to the ullage washing hardware except that it will be providing 99.5% NEA required to wash the oxygen from the fuel and is installed at the fuel tank farm. To facilitate the removal of the dissolved oxygen from the fuel being added to the aircraft, there is a device called an Aspiscrubber that needs to be installed in the fuel delivery line between the fuel storage tanks and the airport fuel supply network. To provide system redundancy for the nitrogen generator, a liquid nitrogen tank will be added to the system.

The paragraphs below provide a description of the equipment required for supplying the NEA at the representative large airport. The focus here is define a feasible architecture to supply the NEA to the aircraft where the recurring, nonrecurring, and maintenance cost can be clearly determined.

Section 1.0 – Architecture for Ullage-Washing Nitrogen System

1.1 NITROGEN GENERATION EQUIPMENT

The nitrogen generator will be supplied as a self-contained unit in a painted, sheet metal weatherproof cabinet.

- Facilities required
- Power consumption = 133 kW
- Power requirements => 3PH 208/220/440 Volts
- Footprint of nitrogen generator = 8 × 7 × 8.3 ft
- Footprint of compressor = 9.2 × 6 × 8 ft
- Nitrogen generator weight: 7,500 lbs.
- Compressor weight: 7,400 lbs.

The nitrogen generator is a polymeric membrane-based system designed for automatic unattended operation. The controls and automatic functions are controlled by the Programmable Logic Controller (PLC). The nitrogen generator is monitored continuously by telephone line and modem to maintain a check of system health, flow delivered, and system status. The system uses an operator interface terminal that allows monitoring and adjusting key process parameters and

the operator interface communicates with the PLC by a serial connection. The main components of the nitrogen generator are listed below.

1.1.1 Membrane Modules

The system incorporates standard commercially available polymeric hollow-fiber membrane modules. The systems will use 6″ diameter modules and these devices are housed in an fiberglass reinforced plastic (FRP) vessel. If 12″ diameter bundles were utilized in the system, they would use an electroplated steel ASME code stamped pressure vessel.

1.1.2 Air Pretreatment System

The system incorporates standard commercially available filtration devices. There is a precoalescing and coalescing filter to remove virtually all water/oil aerosols present in the feed air and a carbon tower to remove oil vapor and any remaining aerosol. The final filtration element is a 0.01 μm dust filter. The coalescing filters are drained automatically through the use of "smart drains" with failure alarms. These failure alarms are transmitted and monitored by the system modem and will shut down the nitrogen generator for membrane module protection.

1.1.3 Process Air Heaters

The system incorporates standard commercially available electric process air heaters with a stainless steel heater body that utilizes a precise temperature control. The basis for the temperature control is a process thermocouple at the inlet of the membrane modules. The heater power is modulated via an all-solid-state control system using either stand-alone proportional controller or full process control loops within the PLC.

1.1.4 Moisture Management

Air exiting the coalescing filters will normally be fully saturated with water vapor. To ensure no subsequent moisture condensation occurs in the carbon tower, piping, or membrane bundles, a small electric preheater is installed at the carbon tower inlet. This electric preheater adds a "dew point margin" to the process air. The dew point margin is then maintained through the process all the way to the membrane modules (even in hot weather when the main heater is off). The carbon tower is also heat traced and continuously powered (even in standby) so that it is warmer than inlet air, even at startup.

1.1.5 Liquid Detector

An optical liquid detector is included in the system to detect any liquid water or oil that might enter the membrane modules. Detection will shut down the nitrogen generator and issue an alarm to the system modem.

1.1.6 Flow/Purity Control

The flow rate of NEA and the nitrogen purity is controlled automatically by the PLC. The system uses an electro-pneumatic control valve, controlled by the PLC.

1.1.7 O_2 Analyzer

The system incorporates standard commercially available Oxygen analyzer. A Teledyne Model 3290 fuel cell (or optional Arelco zirconium) analyzer with relay alarm contacts and a 4-20-ma analog output. Teledyne guarantees cell life for two years. The analog signal is sent to the system modem for telemonitoring purposes.

1.1.8 Product/Vent Valves

The system incorporates standard commercially available on/off valves to positively vent all product gas (and stop any product from reaching the customer) in the case of off-specification purity (>95% in this case). These valves are directly controlled by the PLC.

1.1.9 PLC Controls

The system incorporates standard commercially available industrial PLC. This will utilize one of either two types of PLC control systems. The lowest cost is the same unit and control as used in the M series (GE Fanuc Micro). However, the best control system uses the much more powerful Modicon Micro 612 with an operator interface panel. The better control system yields improved heater control, active purity control, and the possibility of optional flow measurement and turn down.

1.1.10 Ambient O_2 Monitor

An ambient O_2 monitor with warning beacon is installed inside each nitrogen generator for personnel protection in the case of an N_2 leak during maintenance, especially if the sheet metal enclosure door would be closed in bad weather.

1.2 Nitrogen Storage Tank

Each of the nitrogen generators at the airport will require a storage tank to provide an excess capacity for each generator and to keep the N_2 Generator Compressor from cycling to frequently. While the system is designed to provide the peak nitrogen flow rate, preventing the compressor from starting more than three times in an hour is desirable for long, trouble free operation of the system compressors. The tank selected for this application will be an ASME ("U" Stamped) 3,000 gallon storage tank. When the tank pressure falls below 65 psig the nitrogen generator will turn on automatically to insure a continuous flow of nitrogen under all conditions.

- NEA storage tank size – 3,000 gallon – 8ft dia. × 16.2ft tall
- NEA storage tank weight (filled with nitrogen) – 38,000 lbs.

1.3 Nitrogen Delivery Manifold

A nitrogen delivery manifold is required at each terminal to move the NEA from the nitrogen storage tank to the point where the moveable gate attaches to the terminal. The header is required in each concourse and for cost estimating, the header should be considered to extend all

of the way around the outside of the terminal building at the roof level. At each gate the hard pipe should extend from the main pipe out to the pivoting, or moving portion of the gate. The main nitrogen header should be 1-1/2″ diameter pipe and the branch lines from the main header to the movable gate should be made from 1″ pipe. The engineering piping code should be ASME B31.3, Chemical Plant and Petroleum Refinery Piping as a minimum and this specification is commonly used for this type of installation industrially.

1.4 The Moveable Gate Festoon

To move the gas from the nitrogen delivery manifold to the end of the moveable gate or bridge that provides passengers access to the aircraft a festoon is required. Specifically, this device will carry nitrogen from the end of the 1″ branch lines in the delivery manifold, down to the aircraft end of the moveable bridge. This device is called a festoon and will be required to keep the flexible NEA line from becoming tangled when the bridge is moved to meet the aircraft.

1.5 The Hose Reel Assembly

To move the gas from the end of the festoon to the aircraft a length of flexible hose will be required. Also, the flow of gas must be regulated down from the delivery manifold pressures. These pressures will be from 160 psig to 60 psig, depending on the location of the gate to the position of the nitrogen generator, to a pressure suitable for use in inerting the aircraft fuel tanks; for this cost study, we assumed 50 psig. The 50 psig is lower than the normal fuel delivery pressure and should therefore be conservative. The flexible hose will be sized at 1 inch and 75 feet of it will be mounted on a spring return hose reel to keep the hose from becoming tangled with use. The nitrogen line pressure in the hose will need to be regulated from delivery manifold pressures to 50 psig, and a safety valve to be set at 55 psig to never allow the nitrogen to overpressure the fuel tank on the aircraft. There will be a small power requirement (100W) for this hardware because there will be an automated delivery system and the cost of having the power available for the equipment is required. This system will be in the form of a digital/ industrial batch controller and a temperature compensated shutoff valve to provide an accurate nitrogen flow independent of the ambient temperature conditions. This device will allow the nitrogen to be delivered to the aircraft without the aid of an operator to run the nitrogen delivery system. The relief valve, batch controller, and hose reel will be designed into one package and installed under each gate bridge.

Section 2.0 – System Architecture for Commuter Aircraft Concourse

2.1 Commuter Terminal Nitrogen Equipment

The nitrogen generator that will be used for supplying NEA to the commuter aircraft at concourse "C" will be the same as the units that would be used for the remaining concourses at the airport. The description of this equipment can be found in paragraph 1.1.

2.2 Commuter Terminal Distribution Equipment

The primary difference in this equipment from that of the loading bridge mounted equipment is that this equipment will use a slightly different distribution system than the remaining

concourses at the airport. This difference is due to the fact that each gate can service a variety of commuter-sized aircraft causing the moveable gate to require a wide range of motion as compared to the rest of the airport gates. The nitrogen distribution system cannot be piped through a festoon along the side of the aircraft loading bridge as with the rest of the airport.

To provide the nitrogen at the commuter gates, a series of booms will be mounted along the edge of the terminal building that support the nitrogen distribution system and are hard piped into the nitrogen delivery manifold. On each of these booms will be mounted a hose reel assembly as described above in paragraph 1.5. With this change, the nitrogen supply hoses mounted in this manner will be able to service all of the parking positions at the commuter gates.

Section 3.0 – System Architecture for Fuel Scrubbing

3.1 Fuel-Scrubbing Equipment

During flight, as an aircraft gains altitude, the oxygen that is dissolved in the fuel will come out with lowering atmospheric pressure. This can drive the oxygen concentration in the fuel tank ullage to unexpectedly high levels. To combat this phenomenon, the oxygen in the fuel can be scrubbed out before the fuel is added to the aircraft fuel tank. The equipment required to do this is an in-line aspiscrubber and a nitrogen generator, and this equipment will need to be installed on a fixed concrete pad at the airport fuel tank farm.

The nitrogen flow rates for fuel scrubbing 1.2 million gallons of fuel per day is 11,280 pounds per day of 99.5% NEA. The nitrogen generator for supplying NEA to the fuel scrubber, again, is the same configuration as the equipment required supplying nitrogen to the concourses, with an LN2 backup supply to provide system redundancy. To size the equipment, the maximum flow rate of fuel handled by the airport tank farm averaged on a daily basis and the required NEA flow is based off of that. The primary difference in the equipment is the number of membrane modules required to make the 99.5% nitrogen flow rate.

The fuel scrubber (or aspiscrubber) is a stand-alone device and will be supplied as a self-contained unit in a painted, sheet metal weatherproof cabinet and has no power requirements.

- Power requirements => 3PH 208/220/440 Volts
- Power consumption = 119 kW
- Footprint of nitrogen generator = 5 × 9 × 7.5 ft
- Footprint of compressor = 9.2 × 6 × 8 ft
- Footprint of fuel scrubber = 8 × 3 × 5 ft
- Nitrogen generator weight including scrubber: 6,500 lbs.
- Compressor weight: 7,400 lbs.

Part II—Small Airport–Based on Atlantic City International Airport

As with the large aircraft, there are two types of equipment required to support ground-based inerting of commercial aircraft at a small airport. The equipment is of similar design as outlined above except it is configured to supply significantly smaller flow rates. This equipment configuration is based on a nitrogen generator at the airport concourse supplying 95% NEA with

a LN2 system for backup and to help provide flow during the peak periods. The LN2 system will also provide system redundancy and insure 100% equipment up time. The system includes a distribution system, which will allow nitrogen to be provided to the individual aircraft and dispensed at each airport gate.

The other type of nitrogen system required at the large airport is for fuel scrubbing. For the small airport, LN2 will be used exclusively to provide the nitrogen to the fuel scrubber.

Section 4.0 – Architecture for Ullage-Washing Nitrogen System

4.1 Nitrogen Generation Equipment

The nitrogen generator will be supplied as a self-contained unit in a painted, sheet metal weatherproof cabinet and configured as outlined above.

Facilities required

- Power consumption = 10 kW
- Power requirements => 3PH 208/220/440 Volts
- Footprint of nitrogen generator (including compressor) = 2.6 × 5.1 × 4.9 ft
- Nitrogen generator weight (including compressor): 2300 lbs.

The large airport system architecture is essentially the same as the architecture required for a small airport. Below are the differences in the small airport system components as compared to the large airport system. The remainder of the hardware descriptions outlined in section 1, 2, and 3 apply.

4.2 LN2 Tank

The most cost-effective way to provide the nitrogen for both the peak demand flow rate and to provide system redundancy is to use a LN2 supply at the airport. The tank size required is a 500-gallon LN2 tank.

Facilities required

- Power consumption = N/A
- Footprint of tank (including LN2 vaporizer) – 2.6 × 8 × 14 ft
- Unit weight (full): 4,500 Lbs.

4.3 Fuel Scrubbing Equipment

The most cost-effective way to provide the nitrogen for fuel scrubbing is to use a LN2 tank and vaporizer at the airport fuel farm. The tank size required is a 500-Gallon LN2 tank and the facilities required can be seen above in paragraph 4.2. The fuel delivery at small airports is currently accomplished mostly using tank trucks. The assumptions made here are that the fuel can be scrubbed before it is placed on the truck and then blanketed with nitrogen to keep the oxygen from redissolving in the fuel.

4.4 Commuter Terminal Nitrogen Equipment

The nitrogen generator that will be used for supplying NEA to the commuter aircraft for ullage washing is the same hardware that will supply the remainder of the gates at the airport. This difference here is again due to the fact that each gate can service a variety of commuter-sized aircraft causing the moveable gate to require a wide range of motion as compared to the rest of the airport gates. (The same situation here as with the large airport.) Just like with the large airport the nitrogen distribution system cannot be piped through a festoon along the side of the aircraft loading bridge as with the rest of the airport.

To provide the nitrogen at the commuter gates, a hose reel assembly will be mounted near the aircraft staging area. The nitrogen distribution system is hard piped into the nitrogen delivery manifold with part of the pipes being buried in the ground. This configuration should supply enough flexibility so the nitrogen supply hoses mounted in this manner will be able to service all of parking positions at the commuter gates.

APPENDIX E—NONRECURRING COST BREAKOUT FOR ATLANTA HARTSFIELD INTERNATIONAL AIRPORT

TABLE E-1. ATL FACILITY MODIFICATION FOR ULLAGE WASHING (EXCLUDING REGIONAL JETS)

Task/Product		Concourse	Airport Cost
Construction			
	Elevated Support Structure^1	$27,000	$162,000
	Enclosing Structure^2	$8,200	$49,200
	Concrete Supports^1	$5,200	$31,200
	Festoons^3	$221,000	$1,326,000
	Labor	$7,200	$43,200
	Associated Clean-Up	$2,365	$14,190
	F&GC (15%)		$243,869
	SUBTOTAL		$1,869,659
Mechanical			
	1-1/2" S-40 Black Pipe^4	$7,300	$43,800
	1" S-40 Flex Pipe^5	$2,624	$15,744
	Assoc. Fittings and Weld^6	$11,600	$69,600
	Mounting Hdwr^7	$27,700	$166,200
	Hose Reel^8	$450	$63,450
	Metering Unit	$400	$56,400
	Labor	$65,700	$394,200
	Job Expenses & Rentals	$28,900	$173,400
	Bonds	$4,000	$564,000
	F&GC (15%)		$232,019
	Redundancy (T-A, B-C, D-E)^9		
	1-1/2" S-40 Black Pipe		$9,610
	Assoc. Fittings & Weld		$3,335
	Labor		$110,421
	Misc. Job Expenses		$49,700
	F&GC (15%)		$25,960
	SUBTOTAL		$1,977,839
Electrical			
	Required Power to ea. N_2 station		
	Material	$77,200	$463,200
	Labor	$103,550	$621,300
	Required Power for Hose Reels		
	Material	$1,350	$190,350
	Labor	$2,940	$414,540
	Required Power to Scrubbing Pad		
	Materials	$3,200	$3,200
	Labor	$2,350	$2,350
	F&GC (15%)		$254,241
	SUBTOTAL		$1,949,181
	TOTAL		**$5,796,679**

TABLE E-2. ATL REGIONAL JET CONCOURSE MODIFICATION FOR ULLAGE WASHING

Task/Product	Loading Area	Total Cost for Regional Concourse
Construction		
"Boom" Support Device	$18,000	$792,000
Labor	$2,700	$118,800
Associated Cleanup	$1,900	$1,900
F&GC (15%)		$136,905
SUBTOTAL		$1,049,605
Mechanical		
1″ S-40 Flex Pipe^5	$4,700	$4,700
Hose Reel^8	$625	$206,800
Labor	$48,000	$48,000
Job Expenses & Rentals	$21,000	$21,000
Bonds	$4,000	$4,000
F&GC (15%)		$353,807
SUBTOTAL		$638,307
Electrical		
Required Power for Hose Reels		
Material	$1,350	$59,400
Labor	$2,940	$129,360
F&GC (15%)		$188,760
SUBTOTAL		$377,520
TOTAL		**$2,065,432**

TABLE E-3. ATL FUEL FARM MODIFICATION FOR FUEL SCRUBBING

Task/Product		Total Cost
Construction		
	Concrete Pad	$22,800
	Labor	$3,200
	Associated Clean-up	$900
	F&GC (15%)	$4,035
	SUBTOTAL	$30,935
Mechanical		
	Allowance for Associated Hookups	$16,000
	Labor	$18,500
	Bonds	$1,100
	F&GC (15%)	$5,340
	SUBTOTAL	$40,940
Electrical		
	Allowance for Associated Hookups	
	Material	$14,000
	Labor	$24,000
	F&GC (15%)	$5,700
	SUBTOTAL	$43,700
Scrubber		
	Estimated Cost of Scrubber	$50,000
	TOTAL	**$165,575**

APPENDIX F—NONRECURRING COST BREAKOUT FOR ATLANTIC CITY INTERNATIONAL AIRPORT

TABLE F-1. ACY FACILITY MODIFICATION FOR ULLAGE WASHING

Task/Product	Concourse
Mechanical	
1-1/2″ S-40 PVC Pipe	$1,751
1″ S-40 Flex Pipe	$1,415
Festoons (4)	$8,000
Concrete Fill	$500
Concrete Pad	$6,000
Metering Device (6)	$2,400
Hose Reel (6)	$2,700
Handholes (2)	$2,400
Equipment Rental	$2,700
Labor	$16,307
Associated Clean-Up	$2,500
F&GC (25%)	$11,668
SUBTOTAL	$58,342
Electrical	
Required Power to Nitrogen Generator	
Material	$4,110
Labor	$10,098
Equipment	$1,000
Required Power for Hose Reels	
Material	$1,161
Labor	$8,645
Equipment	$1,000
F&GC (25%)	$6,503.55
SUBTOTAL	$32,518
TOTAL	**$90,859**

TABLE F-2. ACY FUEL TRUCK MODIFICATION FOR FUEL SCRUBBING

Task/Product	Total Cost
Construction	
Portable ASPI Fuel Scrubber	$125,000
Truck Modification	$20,000
Eng. Spec. Review	$2,500
Tax (06%)	$7,500
TOTAL	**$155,000**

APPENDIX G—STUDY AIRPORT INFORMATION

TABLE G-1. LIST OF LARGE AIRPORTS FOR THE GBI COST ANALYSIS

Rank	Designator	Airport Name	City, State	Enplanements
1	ATL	Atlanta Hartsfield Int'l Airport	Atlanta, GA	33,249,963
2	ORD	Chicago O'Hare Int'l Airport	Chicago, IL	32,937,402
3	LAX	Los Angeles Int'l Airport	Los Angeles, CA	28,874,012
4	DFW	Dallas-Fort Worth Int'l Airport	Irving, TX	28,152,220
5	SFO	San Francisco Int'l Airport	San Francisco	19,284,485
6	DEN	Denver Int'l Airport	Denver, CO	16,626,361
7	MIA	Miami Int'l Airport	Miami, FL	16,579,269
8	EWR	Newark Int'l Airport	Newark, NJ	15,432,626
9	DTW	Detroit Metropolitan Wayne	Detroit, MI	15,424,000
10	JFK	John F Kennedy Int'l Airport	New York, NY	15,199,099
11	PHX	Phoenix Sky Harbor Int'l Airport	Phoenix, AZ	14,940,339
12	LAS	McCarran Int'l Airport	Las Vegas, NV	14,631,827
13	MSP	Minneapolis-St. Paul Int'l Airport	Minneapolis, MN	14,373,895
14	STL	Lambert-St. Louis Int'l Airport	St. Louis, MO	14,015,360
15	IAH	George Bush Intercontinental Airport	Houston, TX	13,212,686
16	MCO	Orlando Int'l Airport	Orlando, FL	13,044,802
17	BOS	Logan Int'l Airport	Boston, MA	12,449,466
18	SEA	Seattle-Tacoma Int'l Airport	Seattle, WA	12,124,080
19	HNL	Honolulu Int'l Airport	Honolulu, HI	11,596,316
20	CLT	Charlotte/Douglas Int'l Airport	Charlotte, NC	11,334,049
21	LGA	La Guardia Int'l Airport	New York, NY	10,861,757
22	PHL	Philadelphia Int'l Airport	Philadelphia, PA	10,777,410
23	PIT	Pittsburgh Int'l Airport	Pittsburgh, PA	10,306,076
24	SLC	Salt Lake City Int'l Airport	Salt Lake City, UT	10,073,021
25	CVG	Cincinnati/Northern Kentucky Int'l Airport	Covington, KY	9,322,162
26	DCA	Washington National Airport	Washington, DC	7,537,156
27	SAN	San Diego Int'l Airport	San Diego, CA	7,131,902
28	BWI	Baltimore-Washington Int'l Airport	Baltimore, MD	7,008,399
29	TPA	Tampa Int'l Airport	Tampa, FL	6,588,845
30	IAD	Washington Dulles Int'l Airport	Washington, DC	6,467,195
31	PDX	Portland Int'l Airport	Portland, OR	6,318,523
32	FLL	Fort Lauderdale/Hollywood Int'l Airport	Fort Lauderdale, FL	6,088,000
33	CLE	Cleveland Hopkins Int'l Airport	Cleveland, OH	5,710,370
34	MCI	Kansas City Int'l Airport	Kansas City, MO	5,376,439
35	SJC	San Jose Int'l Airport	San Jose, CA	5,016,667
36	SJU	Luis Munoz Marin Int'l Airport	San Juan, PR	4,874,291
37	MEM	Memphis Int'l Airport	Memphis, TN	4,871,479
38	OAK	Metropolitan Oakland Int'l Airport	Oakland, CA	4,447,833
39	MDW	Chicago Midway	Chicago, IL	4,426,424
40	MSY	New Orleans Int'l Airport (Moisant)	New Orleans, LA	4,300,905
41	HOU	William P Hobby	Houston, TX	3,949,236
42	SNA	John Wayne/Orange County Int'l Airport	Santa Ana, CA	3,820,766
43	BNA	Nashville International	Nashville, TN	3,760,270
44	IND	Indianapolis Int'l Airport	Indianapolis, IN	3,574,139
45	SMF	Sacramento Int'l Airport	Sacramento, CA	3,495,461
46	DAL	Dallas Love Field	Dallas, TX	3,413,519
47	SAT	San Antonio Int'l Airport	San Antonio, TX	3,343,818
48	RDU	Raleigh-Durham Int'l Airport	Raleigh/Durham, NC	3,341,684
49	CMH	Port Columbus Int'l Airport	Columbus, OH	3,326,225
50	RNO	Reno/Tahoe Int'l Airport	Reno, NV	3,249,535

Source: FAA DOT/TSC CY1997 ACAIS Database

TABLE G-2. LIST OF SMALL AIRPORT DESIGNATORS FOR THE GBI COST ANALYSIS

ABQ	MYR	FNT	EKO	RDG	LBE	LAF
AUS	SFB	ATW	BIS	OTZ	JLN	PSG
ONT	PNS	ACK	RDM	FLO	VLD	SHD
PBI	LBB	CRW	IDA	ALO	COU	ESC
OGG	GSN	MLB	MKK	LAW	PUW	DUJ
BDL	LEX	EVV	LSE	APF	LMT	MTH
MKE	CAE	FYB	BET	FMN	SAF	MTM
ANC	MAF	EYW	DLH	LWS	MEI	STS
BUR	HSV	ASE	BPT	ACT	SGU	GRI
JAX	SBN	LNK	UNV	GUC	ABR	TEX
RSW	STT	MRY	AEX	PPG	TNI	LHD
PVD	FAT	GPT	ENA	CRQ	XNA	PIR
SDF	ACY	ILM	HDN	OME	IFP	INL
OMA	HPN	AVP	FSM	SPS	IPL	ANI
TUS	PIE	STX	ELM	EAT	HKY	BRD
OKC	ABE	PIA	HXD	ABI	CLM	PVC
TUL	HRL	AGS	ITH	PGV	LNS	FHR
ELP	CRP	TRI	CSG	IPT	GGG	FTW
BUF	TLH	MFT	ACV	AKN	BJI	ISO
GUM	CID	BZN	DRO	EFD	SOP	MCW
GEG	BTR	MGM	CLL	HVN	OTH	SLN
ORF	ISP	LFT	TTN	YNG	MAZ	HIB
BHM	AMA	BGT	SUX	DBQ	MCN	GON
COS	BTV	MSO	BLI	GTR	MGW	LWB
GSO	BGR	FAR	YKM	BTM	COD	SCC
BOI	MOB	PSC	SPI	GRO	HNS	PSE
RIC	SHV	HYA	LYH	SMX	ALW	YAK
LIT	SBA	BMI	GFK	MQT	PQI	WRG
LIH	FAI	JAC	LNY	DLG	VDZ	UCA
ROC	JNU	TBC	LRD	BRW	CMX	VIS
KOA	EUG	RAP	ILE	SJT	JHW	PLB
ALB	LAN	EGE	LCH	PIH	VCT	AHN
DAY	SWF	ERI	ADQ	ABY	CIC	PDT
SYR	SGF	CHO	BRO	MKG	JST	BFD
MHT	MLI	FAY	HLN	BQN	ROW	UIN
GRR	FWA	PFN	L15	ORH	PAH	SHR
DSM	FSD	PHF	YUM	FLG	X95	BFI
TYS	CAK	RST	SBY	RHI	DEC	WST
CHS	GRB	CWA	MOT	OXR	MOD	PGA
ITO	LGB	GNV	HTS	RFD	BQK	RWI
SRQ	ROA	KTN	MVY	TXK	STC	PIB
GCN	BIL	BGM	TYR	PLN	EAU	BFF
MDT	TOL	CMI	SIT	DUT	BRL	RIW
SAV	MFE	DET	EWN	TWF	EWB	PCW
GSP	DAB	SBP	RDD	LEB	CDV	CGX
MSN	MBS	FCA	DHN	PKB	CKB	GCC
PWM	CHA	GJT	MTJ	VQS	CYS	HII
ICT	AVL	GTF	OAJ	HGR	MHK	MWA
JAN	AZO	BFL	SUN	SGY	AOO	FYU
PSP	VPS	MLU	CPR	HOM	TUP	MWH